5 ELECTROMAGNETIC LAMP CONTROL GEAR

5 1 BALLASTS

1 1 Main ballast functions

In chapter 2.1 of this Guide: General aspects, section 2.1: Main ballast functions, the main functions of ballasts have been described. The term **'ballasts'** is generally reserved for current limiting devices, including resistors, choke coils and (autoleak) transformers. Other pieces of auxiliary equipment are **compensating capacitors, filter coils** and **starters or ignitors**. Some systems use an additional series capacitor for stabilisation.
With the components summed up, all control functions which are necessary to operate standard fluorescent lamps can be carried out. Special arrangements, including sequence start, constant wattage or dimming circuits will not be described in this Guide, as such circuits are more and more being replaced by the modern high-frequency (HF)systems.

1 2 Stabilisation

In section 3.2: Stabilisation, the need for current stabilisation in fluorescent lamps has been described, resulting in the following two formulae:

$$I_{lamp} = (\overrightarrow{V_{mains}} - \overrightarrow{V_{lamp}}) / Z_{ballast}$$

and: $P_{lamp} = V_{lamp} \cdot I_{lamp} \cdot \alpha_{lamp}$

where
I_{lamp} = the current through the lamp
V_{mains} = the mains voltage
V_{lamp} = the voltage across the lamp
$Z_{ballast}$ = the impedance of the ballast
P_{lamp} = the power of the lamp
α_{lamp} = a constant called lamp factor

From these formulae it can be concluded that the power of the lamp (and therefore the light output) is influenced by:
- the lamp voltage V_{lamp}, which in turn is highly dependent on the operating temperature (see section 5.3.12: Ambient and operating temperatures) and on the lamp current, according to the negative lamp characteristic (see section 3.2: Stabilisation).
- the lamp current I_{lamp}, which is dependent on the mains voltage (see section 5.3.13: Effects of mains voltage fluctuations), the lamp voltage and the linearity of the ballast impedance.

In order to avoid undesirable variations in light output as a consequence of mains voltage fluctuations, the lamp voltage must be not more than approx. half the value of the mains voltage (100 to 130 V) and the impedance should be as linear as possible.

1 3 Ignition and re-ignition

In chapter 3: Lamps, section 3.3: Ignition, the need for ignition of a fluorescent lamp has been described.

In the case of electromagnetic control gear, a combination of preheating and a high ignition peak is obtained by using a normal choke ballast and a preheat starter or an electronic ignitor.

Energy is supplied to the discharge in the form of electrons. The lamp current, just like the mains voltage, is sinusoidal, with a frequency of 50 or 60 Hz. If the energy flow is zero (at lamp current reversal) the lamp stops burning and in theory would have to be re-ignited.
This could be done by supplying additional energy to the electrodes via a higher lamp voltage, the way it is done when initially starting the lamp. But from the moment the lamp has reached its stationary condition, the lamp voltage is constant.
And yet, in practice the lamp does not extinguish at current reversal. Why not?
The phase shift introduced by the inductive element of the ballast ensures that the mains voltage is not zero at that moment. Because of the inductive properties of choke coil ballasts a phase shift φ occurs between the mains voltage and the lamp current (see Fig. 102). So, at the moment of current reversal the lamp voltage would be equal to the mains voltage, since the voltage over the ballast is nil. The difference (gap) between the mains voltage and the average lamp voltage as a consequence of the phase shift ensures proper re-ignition of the lamp at the moment the current passes the point of reversal (zero-point A in figure).

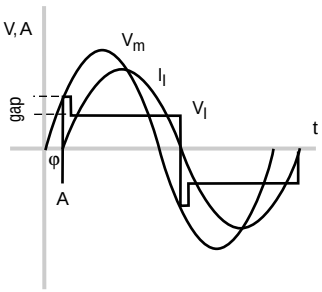


Fig. 102. Phase shift between supply voltage and lamp current (and lamp voltage) in a discharge lamp with an inductive ballast. In the case shown, the supply voltage is sufficiently high for re-igniting the lamp after every current reversal.

1.4 *Types of ballasts*

1 Resistor ballasts

Current limitation by means of resistor ballasts is a very uneconomic form of current limitation, because in the resistor electrical energy is dissipated in the form of heat. Nevertheless, until the advent of electronic circuitry, use of a series resistor was the only way of stabilising fluorescent lamps operated on DC, for example the 'TL'R lamp (see Fig. 103). For stable operation on a resistor ballast, it is necessary that the supply voltage be at least twice the lamp voltage under operating conditions. This means that 50 per cent of the power will be dissipated by the ballast. A considerable improvement in efficiency can, however, be achieved by using a resistor with a very pronounced positive temperature characteristic (an ordinary or specially constructed incandescent lamp serves well for this purpose).
A temperature-dependent resistor compensates for variations in the lamp current resulting from variations in the mains voltage, which means

that the no-load voltage need be no more than 25 to 30 per cent higher than the lamp voltage. This is also the proportion of the power dissipated by the ballast compared to the total circuit power.

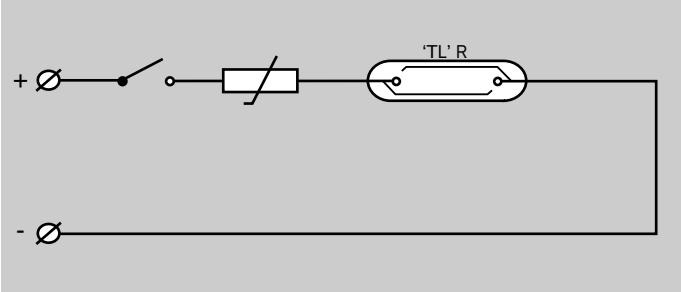


Fig. 103. Schematic diagram of a fluorescent lamp operated on a resistor ballast in a DC circuit.

2 Capacitor ballasts

A capacitor used as a ballast causes only very little losses, but cannot be used by itself, as this would give rise to very high peaks in the lamp current wave form at each half cycle. Only at very high frequencies can a capacitor serve satisfactorily as a ballast.

3 Inductive ballasts or chokes

Choke coils are frequently used as current limiting devices in gas-discharge lamp circuits (see Fig. 104). They cause somewhat higher losses than a capacitor, but produce far less distortion in the lamp current at 50 Hz. Moreover, in combination with a switch starter, they can be made to produce the high voltage pulse needed to ignite the lamp.
In practice, a choke ballast consists of a large number of windings of copper wire on a laminated iron core. It operates on the self-inductance principle. The impedance of such a ballast must be chosen in accordance with the mains supply voltage and frequency, the lamp type and the voltage of the lamp, to ensure that the lamp current is at the correct value. In other words: each type of lamp requires for each supply voltage its own choke as a ballast with a specific impedance setting.
Heat losses, occurring through the ohmic resistance of the windings and hysteresis in the core, much depend upon the mechanical construction of the ballast and the diameter of the copper wire.
The right ballast for a given lamp and supply voltage should be chosen by consulting documentation and/or ballast markings.
The Philips standard range of ballasts is for supply voltages of 220/230/240 V and for frequencies of 50/60 Hz.

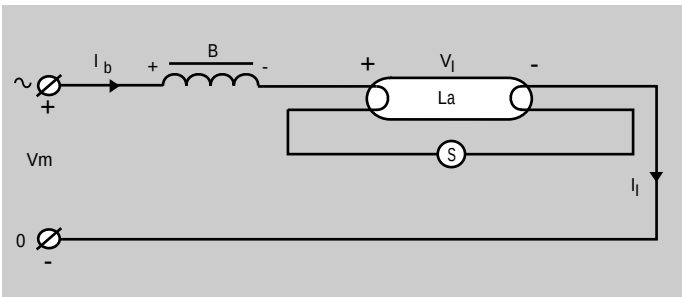


Fig. 104. Schematic diagram of a fluorescent lamp operated on a choke ballast in an AC starter circuit.

The most important value for stabilisation is the ballast impedance. It is expressed as voltage/current ratio in ohm (Ω) and defined for a certain mains voltage, mains frequency and calibration current (normally the nominal lamp current).

Chokes can be used for virtually all discharge lamps, provided that one condition is fulfilled: the mains voltage should be about twice the arc voltage of the lamp. If the mains voltage is too low, another type of circuit should be used, like the autoleak or constant-wattage circuits.

The advantages of a choke coil are:
- the wattage losses are low in comparison to those of a resistor,
- it is a simple circuit: the ballast is connected in series with the lamp.

Disadvantages of a choke coil are:
- the current in a lamp with choke circuit exhibits a phase shift with respect to the applied voltage, the current lagging behind the voltage (see also section 5.3.4: Power factor correction).
- a high starting current: in inductive circuits the starting current is about 1.5 times the rated current.
- sensitivity to mains voltage fluctuations: variations in the mains voltage cause variations in the current through the lamp.

1.5 *Ballast specification and marking*

There are two ways of selecting the right ballast for a certain lamp and/or to compare various ballasts:
1) the ballast marking,
2) the manufacturer's documentation.
As all ballasts have to comply with the norm IEC 920/921 some data has to be marked on the ballast and other data can be mentioned in the documentation.

On the ballast can be found:
- marks of origin, such as the manufacturer's name or trade mark, model or reference number, country of origin, production date code,
- rated supply voltage and frequency, nominal ballast current(s),
- type(s) of lamp with rated wattage,
- type(s) of ignitor with wiring diagram and peak voltage if this exceeds 1500 V,
- t_w and Δt (see section 5.1.6),
- max. cross-section of mains or lamp cable; e.g. 4 □ means 4 mm2,
- symbols of the officially recognised certification institutes, such as VDE, SEMKO, SEV, KEMA, if applicable; CE marking for safety,
- in case of an independent ballast: the symbol ⓘ; an independent ballast is a ballast which is intended to be mounted separately outside a luminaire and without any additional enclosure,
- a symbol like → top if there are mounting restrictions,
- F-marking ▽F if the ballast fulfils the IEC F-requirements; that means it is suitable to be mounted directly on normally flammable surfaces,
- TS, P-marking ▽P or ▽* if the ballast is thermally protected (* = thermo-switch temperature in degrees Celsius),
- indication of terminals: L for single phase, N for neutral, ⏚ for protective earth (PE), ⏚ for functional earth,

- rated voltage, capacitance and tolerance of separate series capacitor.

In the documentation can be found:
- weight,
- overall and mounting dimensions,
- power factor (λ, P.F. or cos φ),
- compensating capacitor value and voltage for λ = 0.85 or 0.9,
- mains current nominal and during running-up, both with and without power factor correction,
- watt losses (normally in cold condition),
- description of version, e.g. open impregnated, 'plastic' encapsulated, potted or compound filled.

This information suffices to find the right ballast for a certain application. Additional information can be obtained on request or can be found in special application notes. Philips ballasts are designed for use with IEC standardised fluorescent lamps.

16 *Maximum coil temperature t_w and ΔT*

A ballast, like most electrical components, generates heat due to its ohmic resistance and magnetic losses. Each component has a maximum temperature which may not be exceeded. For ballasts it is the temperature of the choke coil during operation that is important. The maximum permissible coil temperature t_w is marked on the ballast. Coil insulating material, in combination with lacquer, encapsulation material etc., is so chosen that below that temperature the life specified for the ballast is achieved. A t_w value of 130 ºC is usual nowadays with a coil insulating class F (150 ºC) or class H (180 ºC). Under standard conditions, an average ballast life of ten years may be expected in the case of continuous operation at a coil temperature of t_w ºC. As a rule of thumb, a 10 ºC temperature rise above the t_w value will halve its expected life (see Fig. 105). If, for instance, the operating temperature is 20 ºC above the t_w value, one may expect a ballast life of 2.5 years of continuous operation. If no t_w value is marked on the ballast, a maximum of 105 ºC is assumed for the coil temperature.
As the ballast normally does not function continuously, the actual life of the ballast can be very long. It also takes some hours before the thermal equilibrium is reached in the ballast, which again increases the practical ballast lifetime.
To verify the t_w marking, accelerated lifetime tests are done at ballast temperatures above 200 ºC for 30 or 60 days.

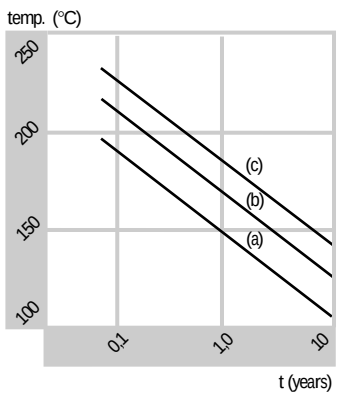


Fig. 105. The nominal life of choke coils in relation to the permitted rated maximum operating temperature of a ballast winding t_w, dependent on insulation material: a) class A: t_w 105 ºC, b) class E: t_w 120 ºC, c) class F or H: t_w 130 ºC.

1.6 Maximum coil temperature t_w and ΔT

Another value marked on the ballast is the coil temperature rise Δt. This is the difference between the absolute coil temperature and the ambient temperature in standard conditions and is measured by a method specified in IEC Publ. 920 (EN 60920). Common values for Δt are from 50 to 70 degrees in steps of 5 degrees.
The coil temperature rise is measured by measuring the ohmic resistance of the cold and warm copper coil and using the formula:

$$\Delta t = \{(R_2 - R_1)/R_1\} . (234.5 + t_1) - (t_2 - t_1)$$

or: $t_c = R2/R1 . (t_1 + 234.5) - 234.5$ (IEC 598-1 Appendix E)

where R_1 = initial cold coil resistance in ohm
R_2 = warm coil resistance in ohm
t_2 = ambient temperature at measuring R_2 in Celsius
t_1 = initial ambient temperature at measuring R_1 in Celsius
t_c = calculated warm coil temperature in Celsius
$\Delta t = t_c - t_2$ in Kelvin
The value 234.5 applies to copper wire; in case of aluminium wire, the value 229 should be used.

So a ballast marked with t_w 130 and Δt 70, will have the specified 10 years average life in continuous operation at standard conditions at an ambient temperature of 130 - 70 = 60 ºC. When the ambient temperature around the ballast is higher, a shorter ballast life has to be accepted or sufficient air circulation or cooling has to be applied. The so-called ambient temperature mentioned in this chapter is not the room or outside temperature, but the temperature of the micro-environment of the ballast. Built into a luminaire or ballast box the air temperature around the ballast is higher than the outside ambient temperature. This higher temperature has to be added to the coil temperature rise Δt to find the absolute coil temperature: $t_c = t_2 + \Delta t$.

Additionally, a third temperature figure can be mentioned on the ballast: the ballast temperature rise in abnormal conditions, again measured according to specifications like EN 60920. In short: it is the winding temperature rise at 110 per cent mains voltage when the glow-switch starter, belonging to the system, is short-circuited.

The marking of the three temperature markings should be :

Δt ** / *** / t_w *** with * = figure

Example: Δt 70 / 140 / t_w 130.

Watt losses

Ballast losses normally are published as 'cold' values, meaning that the ballast is not energised or only very shortly before and the ballast winding is at ambient temperature (25 ºC). In practice the ballast will reach more or less the marked Δt value and then the copper resistance is approx. 25 per cent higher than in the 'cold' situation. Therefore the 'warm' losses in practice will be 10 - 30 per cent higher than the published values.

As in some applications the power consumption is of prime importance, there are low-loss ballasts for the major lamp types 'TL'D 18, 36 and 58 W (BTA**L31LW). The 18 and 36 W LW ballasts are bigger than the standard types, resulting in lower ballast temperatures and 25 to 30 per cent less ballast watt losses. Due to practical restrictions the BTA 58L31LW type could not be made bigger. The 15 per cent lower ballast losses are the result of a better iron lamination quality, while the ballast temperatures are only slightly lower than those of the standard types.

STARTERS

5 2 2 1 Main starter function

Fluorescent lamps do not ignite at mains voltage. To ignite the lamps, a starter is applied to preheat the lamp electrodes and to give a peak voltage high enough to initiate the discharge.
So in fact there is only one basic function for a starter: to deliver the ignition voltage to start the discharge in a fluorescent lamp in a proper way. After ignition the starter has to stop producing ignition peaks. This can be obtained by sensing the lamp voltage or lamp current and/or by a timer function.

2 2 Starter types

There are two types of fluorescent lamp starters:

1 Glow-switch starters

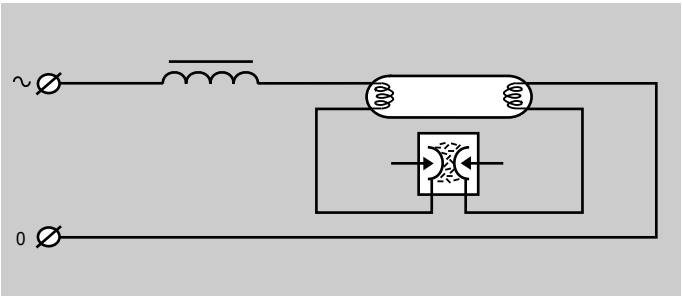
The glow-switch starter consists of one or two bimetallic electrodes enclosed in a glass container filled with noble gas. The starter is connected parallel across the lamp in such a way that the preheat current can run through the lamp electrodes when the starter is closed (Fig. 106). At the moment of switching on the mains voltage, the total mains voltage is across the open glow-switch starter. This results in a glow discharge starting between the bimetallic electrodes of the starter. The glow discharge causes a temperature increase in these bimetallic electrodes, resulting in the closure of the electrodes of the starter. During this closure the lamp electrodes are preheated by the short-circuit current of the ballast. After closure the temperature of the starter electrodes decreases and the starter re-opens. At the moment of re-opening, the current through the ballast is interrupted, causing a peak voltage over the lamp electrodes high enough for lamp ignition. This peak voltage depends on the inductance of the choke, the level of the short- circuit current and the speed of the opening of the glow-switch electrodes. In formula:

Peak voltage: $V_{peak} = L\ dI/dt$

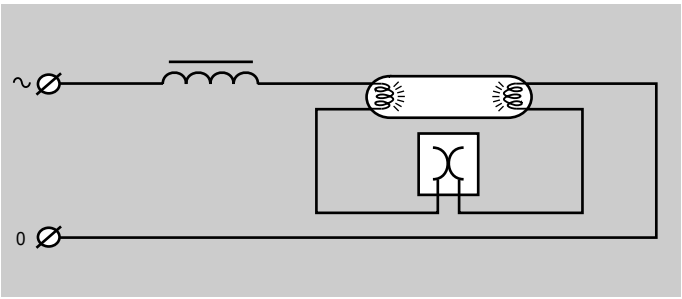
The minimum specified peak voltage depends on the type and is between 800 and 900 V.
If the lamp electrodes are not yet hot enough or the peak voltage is not high enough, the glow-switch starter will resume the whole

starting process again until the lamp ignites. If the lamp will not ignite (end of life) the starter will continue producing peaks (flickering) until the mains voltage is switched off or until the electrodes of the glow-switch starter stick together. In the latter case the short-circuit current is continuously running through the lamp electrodes, which can be seen at the glowing lamp ends.

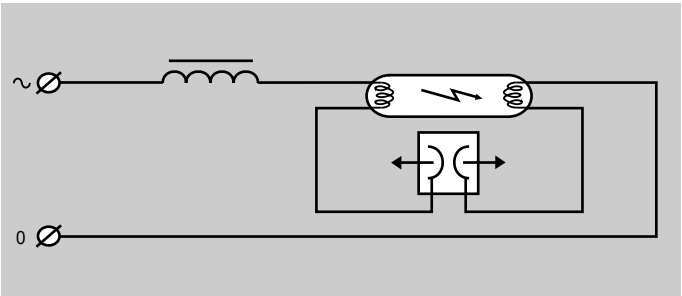
Fig. 106. Working principle of a glow-discharge starter circuit.



1. The heat from the discharge in the starter bulb causes the bimetallic electrodes to bend together.



2. When the bimetallic electrodes make contact, a current starts to flow through the circuit, sufficient for preheating the electrodes of the fluorescent lamp.



3. The bimetallic electrodes cool down and open again, causing a voltage peak, which ignites the fluorescent lamp.

Once the lamp is properly ignited, the lamp voltage is too low for a glow discharge between the starter electrodes. So these electrodes stay 'cool' and in open position.
A capacitor across the starter electrodes prevents radio-interference of the lamp.

There are five types of glow-switch starters, specified for a certain mains voltage and/or lamp wattage (S2-10-11-12-16).There are also resettable glow-switch starters: SiS2, Si S3 and SiS10. These starters switch off after a certaintime in case the lamps do not ignite and have to be reset manually by a push button. Switching the mains supply does not reactivate a switched-off resettable starter.

2 Electronic starters

In principle the electronic starter or ignitor is working in the same manner as the glow-switch starter. But now the switching does not come from bi-metallic electrodes, but from a triac.
The electronic circuit in the starter gives a well-defined preheat time (1.7 sec) for the lamp electrodes and, after the preheat, a well-defined peak voltage, which ensures optimum lamp ignition. The heart of the electronic starter is a customized integrated circuit, containing the intelligence of the product. It makes the starter switch off after seven unsuccessful ignition attempts, so it is called 'flicker free'.
The electronic starter also contains an over-heating detection by means of a PTC resistor, to switch off in case the starter becomes too hot (e.g. with a short-circuited ballast). This second stop function resets after approx. 4 minutes.
The electronic starter extends the lamp lifetime up to 25 per cent on account of the well-defined preheat time. The exact digital timing makes the electronic starter independent of mains voltage fluctuations.
In the Philips programme there are two types of electronic starters: one in the canister of the glow-switch starters (two-pin types S2-E and S10-E Perform version), and one in a plastic housing (four-pin type ES08).

2 3 *Lifetime*

The lifetime of fluorescent lamp starters is expressed in the number of switches.
At present the glow-switch starters have a lifetime of 10 000 switches or more, while the electronic starters have a lifetime of 100 000 switches or more.

SYSTEMS 5 3

3 1 *Components*

A customer primarily needs a solution to his lighting requirements. Basically, he needs two things to obtain an installation which completely fulfils his specifications: a design and components. To make sure that the installation works properly under all circumstances, the right components must be chosen and selected in combination with each other.
In principle the following components are required in a lighting installation:
- lamps,
- lampholders,
- luminaires,
- gear (ballasts, starters),
- compensating capacitors,
- cabling,
- fusing and switching devices,
- filter coils (if necessary),
- dimming equipment (if possible and required).

Information about **lamps** can be found in the lamp documentation, where also the type of **lampholder** or lamp cap is mentioned. Be sure to use the appropriate lampholder, as there are many different types. Lamp types with different wattage are in principle not interchangeable in a certain circuit, even though they may have the same lamp cap and do fit in the same lampholder.
In some lamp types the glow-switch starter is incorporated in the lamp base (2-pin version PL). In the SL family the total electric circuit is incorporated with the lamp in the outer shell (see Fig. 107).

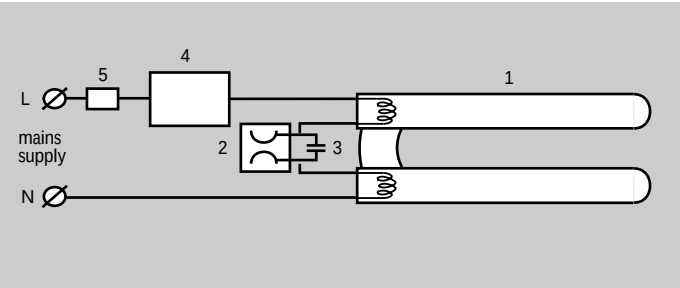


Fig. 107. The circuit of an SL lamp consists of the following components: 1. Discharge tube, 2. Starter, 3. Capacitor, 4. Ballast, 5. Thermal protector.

In the **luminaire** documentation, information can be found on which lamp types can be used. When installing other than specified types, electrical, thermal or lighting problems will arise. In the luminaire documentation it can also be found if the gear is incorporated in the luminaire and what the cable entries and connections are.

In the **gear** documentation, information can be found about the electrical terminals and the electrical diagrams. Also the value and the voltage range of **capacitors** is mentioned here.

The remaining system-related components and subjects mentioned above will be described in the following sections.

3.2 *Capacitors*

Two types of capacitors are possible in fluorescent lamp circuits. One type is the **parallel** compensating capacitor for power factor improvement, connected across the mains. The second type is the **series** capacitor which also determines the lamp current.
Series capacitors are used in capacitive or duo circuits.

In installations with fluorescent lamps of more than 25 W, capacitors are necessary for power factor correction, as the power factor of an inductively stabilised circuit is only approx. 0.5. Power factor compensating capacitors are connected across the mains supply voltage (parallel compensation) between phase and neutral (220/240 V).
In the relevant ballast documentation figures can be found for the capacitor value in microfarad (µF) for a certain combination of lamp and supply voltage to achieve a power factor of ≥ 0.9.
Every user can in fact create his own solution for obtaining the necessary capacitance.

To do things well, some aspects have to be considered:
- First of all, capacitors for discharge lamp circuits have to fulfil the requirements as specified in IEC publications 1048 and 1049. The use of PCB (chlorinated biphenyl) is forbidden.
- It is recommended that capacitors which have some approval marks, such as VDE, KEMA, DEMKO or ENEC be used.
- Normally every lamp circuit is compensated by its own capacitance. Only in some special cases group or central compensation for more lamp circuits can be a better solution.
- In case of failure of the parallel capacitor (open or short-circuited) the lamp behaviour is not affected. Regular control of the mains currents and/or power factor (λ or cos φ) is advisable.
- In case of failure of the series capacitor the lamp behaviour is immediately affected. This type of capacitor must create an open circuit in case of failure, so that the lamp will be extinguished.
- The lifetime of capacitors depends on the capacitor voltage and capacitor case temperature. Therefore capacitors with the correct voltage marking (parallel 250 V with a maximum capacitance tolerance of +/- 10% or series 450 V with a maximum capacitance tolerance of +/- 4 %) and within the specified temperature range (normally - 25 ºC to + 85 or 100 ºC) should be used.
  Used within the specifications, capacitors with the VDE marking will have a lifetime equal to that of ballasts: 30 000 hours or 10 years.
- If a specified parallel capacitance value occasionally is not available, the next higher value can be used, provided that the value is not more than 20 per cent above specification.

Two general types of capacitors are currently in use: the wet and the dry type.
Wet capacitors available today contain a non-PCB oil and are equipped with internal interrupters to prevent can rupture and resultant oil leakage in the event of failure. So a clearance of at least 15 mm above the terminals has to be provided to allow for expansion of the capacitor. In case of failure, these capacitors will result in an apparent open circuit, which means the mains current drawn by the circuit approximately doubles in case of a parallel capacitor. This can cause a fuse to blow, a circuit breaker to open, but will have no further detrimental effect. Used as a series capacitor, the open circuit of the failing capacitor will extinguish the lamp.

Dry, metallised-film capacitors are relatively new to the lighting industry and are not yet available in all ratings for all applications. However, they are rapidly gaining popularity because of their compact size and extreme ease of installation and are, therefore, widely used nowadays. During its lifetime this type of capacitor gradually loses its capacitance, resulting in a gradually increasing mains current when used as a parallel capacitor. In the end the capacitor acts like an open circuit. For the series capacitor a capacitance loss of only 5% during its lifetime can be accepted, so the dry capacitor is not recommended for series applications.
Dry capacitors are more sensitive to voltage peaks than wet capacitors. In critical applications (mains supply containing peaks, frequent switching, high level of humidity or condensation) the wet capacitor is advisable.

Capacitors for lighting applications must have a discharge resistor connected across the terminals to ensure that the capacitor voltage is less than 50 V within 1 minute after switching off the mains power. In special cases the voltage level must be 35 V within 1 second, see IEC 598-8.2.7.

3.3 *Filter coils*

In some countries, including Belgium, the Netherlands and France, the electric distribution network is used for transmitting messages under responsibility of the local energy supply authority.
Signals are sent over the electricity supply network for a number of purposes: to switch road lighting, to call up fire brigades and the police, to switch night-tariff kWh-meters, and so on. It is important, therefore, that this signalling system is not disturbed, which may occur when parallel power factor correction capacitors for lamp circuits are employed. Capacitors present a low reactance to the 200-1600 Hz signals employed for signalling, with the result that these are in danger of being short-circuited in a capacitive circuit. To avoid this, a coil must be connected in series with the capacitor connected parallel to the mains. This filter coil, as it is termed, presents a reactance that increases with rising signal frequency. The coil reactance is therefore chosen such as to balance out the reactance of the capacitor at 200 Hz (the resonance frequency, see Fig. 108).
For currents with a frequency of 50 Hz the circuit is predominantly capacitive, which is necessary for power factor correction. Above 200 Hz the circuit becomes predominantly inductive, which is necessary for the blocking of audio-frequency signals. At 200 Hz the impedance is only formed by the ohmic resistance, mainly of the filter coil.
As can be seen from the graph, the filter coil is effective for audio signals of 300 Hz and higher, because then the impedance of the coil/capacitor combination is higher than the impedance of the sole capacitor. Filter coils should not be used when the audio signals are 300 HZ or lower.

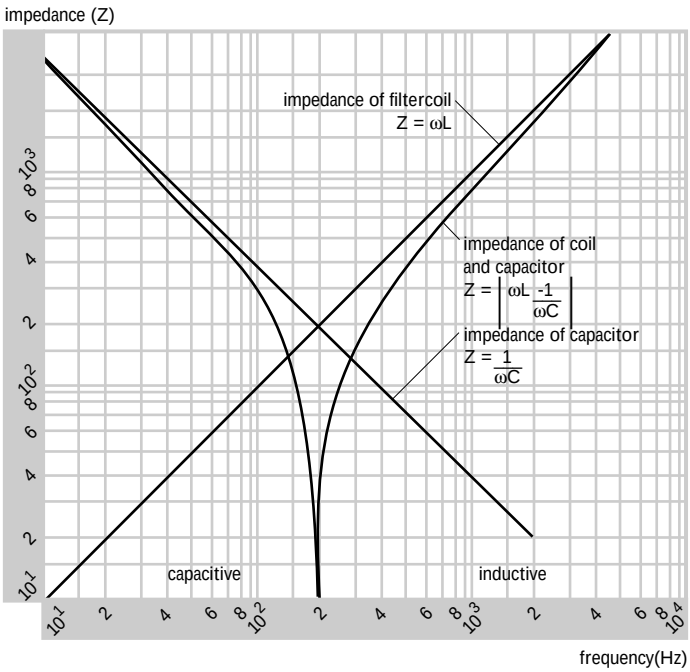


Fig. 108. Impedance of a filter coil, a capacitor and a coil/capacitor combination as a function of frequency.

There are other advantages to be gained from employing filter coils. The parallel capacitor can cause troublesome switching phenomena to occur, which can give rise to very large current surges. Although these surges are of only very short duration (a few milliseconds), they are nevertheless sufficient to cause switching relays to stick or circuit breakers to switch off. The filter coil serves to prevent this problem by damping the very short, high amplitude pulses in the current.
The type of filter coil needed depends on the capacitance of the capacitor employed. So, in fact every capacitor needs its own filter coil. But in some cases it is possible to group the capacitors and match them with the corresponding filter coil. For example: two capacitors of 4 µF parallel can be connected in series with one filter coil for 8 µF (see Fig. 109).
Also central filter coil systems exist where a filter system in the supply system is blocking the applied signalling frequencies.
Although the voltage across the filter coils is rather low (approx. 14 to 20 V), the filter coils have to be regarded as ballasts, as they are directly connected to the mains. They also cause some additional watt losses.
The amount of third and fifth harmonics in the mains current will rise in cases where the mains supply voltage is disturbed with third or fifth harmonics, when applying a filter coil. The total impedance for the combination of capacitor and filter coil is lower than the impedance of the sole capacitor for these frequencies (see section 5.3.9: Harmonic distortion and Fig. 108).

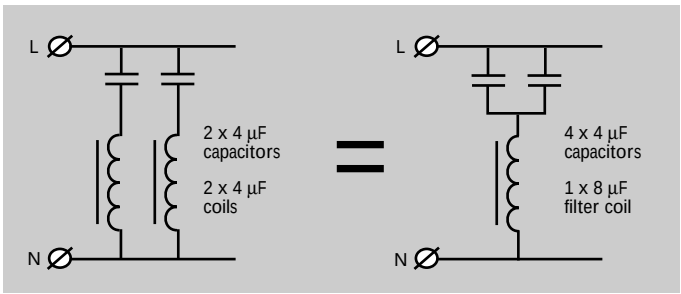


Fig. 109. Different ways of grouping capacitors to match them with the corresponding filter coil.

3.4 *Power factor correction*

Circuits with gas-discharge lamps are stabilised with inductive ballasts and compensated for a good power factor with a parallel compensating capacitor (mono-compensation, Fig. 110).
Without the capacitor the inductive ballast causes a phase shift of the current, which is lagging behind the applied voltage.

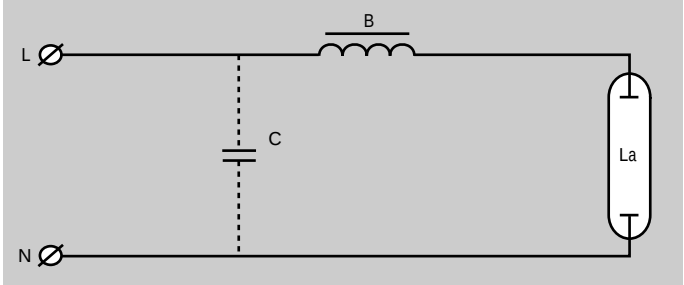


Fig. 110. Power factor correction with a parallel compensating capacitor.

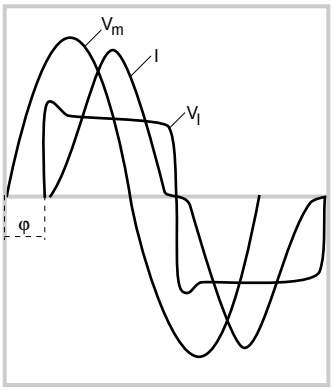


Fig. 111. Lamp current (I_l), lamp voltage (V_l) and mains voltage (V_m).

This can be seen in Fig. 111, which is showing the lamp current I_l, the lamp voltage V_l (both in phase with each other) and the sinus form of the mains voltage V_m.
The power factor of the circuit can be calculated by dividing the total wattage by the product of mains voltage and current. In formula:

$$P.F. = (W_l + W_b)/(V_m \cdot I_m) \qquad (1)$$

Without the parallel compensating capacitor the power factor of a gas-discharge circuit is approx. 0.5.
For the fundamentals of the voltages and current a so-called vector diagram can be made (see Fig. 112). Lamp voltage and lamp current are in phase and the voltage across the ballast is leading 90 electrical degrees to the current. The vectorial sum of lamp voltage and ballast voltage gives the mains voltage. Now we see that $\cos \varphi = V_l/V_m$, which is less accurate than (1).
In any case the energy supply authority has to deliver an apparent power of $V_m \cdot I_l$ to the system on which the distribution network must be based (cabling, transformers).
The energy meter only records the in-phase component $V_m \cdot I_l \cos \varphi$, so the supply authority does not get paid for the so-called 'blind' part: $I_l \sin \varphi \cdot V_m$ (Fig. 113).

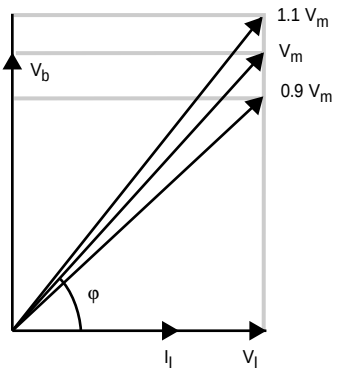


Fig. 112. Example of a vector diagram showing lamp voltage and lamp current in phase.

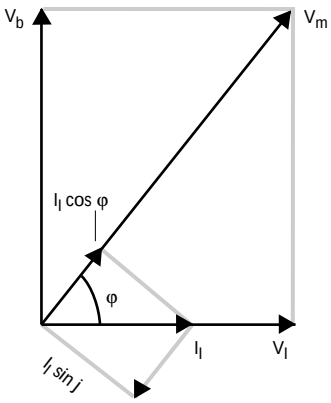


Fig. 113. Uncompensated circuit with lamp current and mains voltage out of phase.

For this reason, the supply authority demands compensation of the phase shift.
Where in general the 'unadjusted' power factor is about 0.50, it has to be compensated to a minimum of 0.85 or even 0.90. This is achieved by adding a capacitor across the mains. In contrast to an inductive

ballast, the capacitor current is leading 90 electrical degrees to the capacitor voltage (which is the mains voltage). So the capacitor current has the opposite direction of $I_l \sin \varphi$ (see Fig. 114).

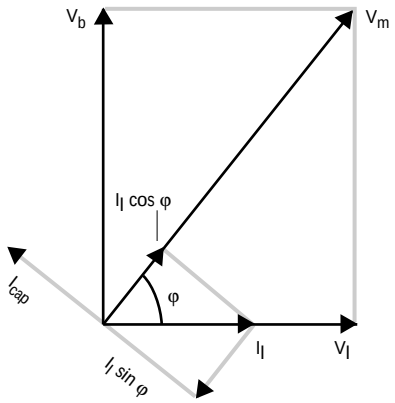


Fig. 114. Compensated circuit.

Maximum compensation is achieved when the current through the capacitor $I_c = I_l \sin \varphi$; then the power factor is 1. This is purely theoretical, as the vector diagram is only valid for the fundamentals of the currents. Due to distortion in the lamp current (see section 5.3.9: Harmonic distortion), the maximum practical power factor is between 0.95 and 0.98. This explains the difference between power factor and cos φ.
The power factor is the result of the quotient of the actual wattage and the product of mains voltage and mains current, including the harmonics, and can be calculated as follows:

Power factor (P.F.) = total wattage/mains voltage . mains current

The angle φ is the phase shift angle between mains voltage and mains current and can be found and calculated by means of the vector diagram. This is only valid for the fundamentals and does not take into account the harmonics.

The same analogy is valid for the lamp: there is practically no phase shift between lamp voltage and lamp current: both are zero at the same time. So the phase angle α is zero and cos α = 1.
The product of lamp voltage and lamp current does not equal the lamp wattage; the difference is called lamp factor:

Lamp factor = lamp wattage / lamp voltage . lamp current

and has a value between 0.8 and 0.9. For the same lamp type the lamp factor is higher for higher wattages, identical to the lamp efficacy.
Typical capacitor values for this parallel compensation (also sometimes called mono-compensation) for a 50 Hz mains are 4.5 µF for a 36 or 40 W fluorescent lamp and 6.5 µF for a 58 or 65 W lamp.

A second method for compensation is the so-called duo-circuit. This is employed for pairs of lamps, as for example in two-lamp luminaires. Here the capacitor is placed in series with one of the ballasts (see Fig. 115).

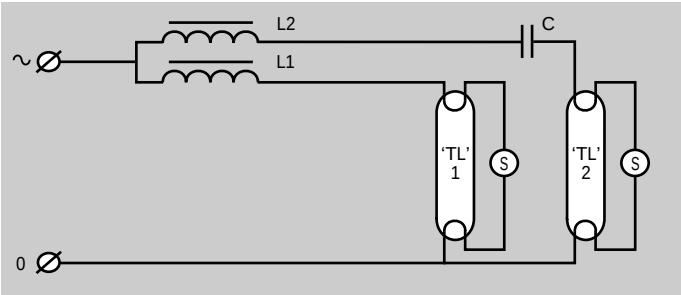


Fig. 115. Duo-circuit with the capacitor placed in series with one of the ballasts.

The series capacitor has an impedance which is twice the normal ballast impedance, resulting in a power factor of approx. 0.5 capacitive for one branch. Together with the power factor of 0.5 inductive for the other branch, the total power factor of the two branches is approx. 0.95. With a normal 230 V supply, the voltage across the capacitor is about 400 V. To fulfil all relevant requirements, the tolerance on the capacitor capacitance value has to be within +/- 4 %. The nominal value of the capacitance is depending on the mains supply voltage, the applied ballast impedance and the lamp wattage. Typical values are 3.4 µF for a 36 W and 5.3 µF for a 58 W lamp.
Compared with the mono-compensation the advantages of this way of compensation are:
- only one capacitor is required for two lamps, instead of two,
- the capacitive branch is less sensitive to supply voltage deviations, as it has a constant current characteristic,
- in case of actadis signals (see section 5.3.3: Filter coils) these signals are not influenced, so no filter coil is needed.

Disadvantages of duo-compensation are:
- series capacitors are more expensive than parallel capacitors,
- the lamp power and so the light output from the capacitive branch is slightly higher than that from the inductive branch.

In some countries, practically all multi-lamp luminaires have built-in duo-circuits for each pair of lamps (also called a 'dual-lamp' or 'lead-lag' circuit). Mono-compensation, on the other hand, is generally left to the installer, although there are also single-lamp luminaires available with the compensation built in.

The capacitive circuit has a so-called 'constant current characteristic'. This can be explained by the non-linearity of the inductive ballast. Suppose that the impedance of the ballast is 400 Ω, which varies, say 10 per cent when the ballast voltage changes 10 per cent (see Fig. 116). With the inductive ballast the resulting (lamp) current at 90 per cent mains voltage will be lower:
A: as result of the lower mains voltage,
B: as result of the higher impedance.

With the capacitive ballast combination, the resulting impedance of inductive ballast and capacitor is reacting in just the opposite way: at lower mains voltage the total impedance is also lower. This results in a nearly constant current.

Mains voltage	90 %		100 %		110 %	
Circuit	Ind.	Cap.	Ind.	Cap.	Ind.	Cap.
Z ballast (Ω)	440	440	400	400	360	360
Z capacitor (Ω)		800		800		800
Z result (Ω)	440	360	400	400	360	440

Therefore the behaviour of the inductive and capacitive branch of a duo-circuit is different at mains voltage deviations and deviations of the ambient temperature. This can be seen rather well in a duo-luminaire.

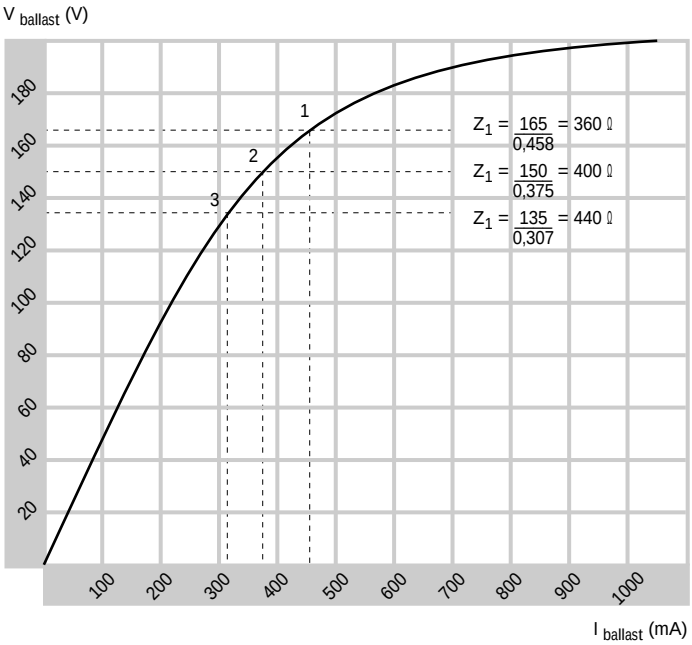


Fig. 116. Voltage/current characteristic of an inductive ballast (example).

3.5 *Series connection of lamps*

Under certain conditions it is possible to operate two lamps in series on a common ballast (see Fig. 117). A prerequisite for such operation is that the sum of the operating voltages of the lamps is not higher than approximately 60 per cent of the supply voltage. This means that two lamps, each with an arc voltage of no more than 65 volt, can be connected in series via a common ballast to the 220/240 V mains. This restricts the maximum lamp length to 600 mm (2 ft), or the lamp power to 18/20 W (26 or 38 mm diameter lamps only).
The series circuit can be compensated in the normal way by using a parallel or series capacitor.

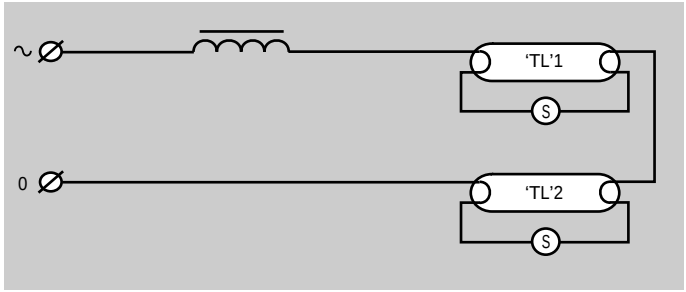


Fig. 117. Tandem circuit with two lamps in series on a common ballast.

Parallel connection of two lamps on a common ballast is impossible because of the negative characteristic of the fluorescent lamp. All the current would flow through the lamp with the lower arc voltage. Moreover, once the first lamp is ignited the lamp voltage is too low for the ignitor of the second lamp to ignite this lamp.

3.6 *Neutral interruption and resonance*

Normally each lamp circuit has its own compensating capacitor. In this way every luminaire can be switched separately without influencing the power factor. For the same reason lamp circuits based on phase-neutral (230 V), are compensated with capacitors connected between each of the phases and neutral.
In the phase-neutral network failure of one phase has no other effect than to switch off the circuits on that phase. But if the neutral is not connected, resonance will occur. For example, the current from phase L1 via ballast and lamp 3 (see Fig. 118) can pass via capacitor C1 to phase L3. So lamp 3 is energised by 400 V and stabilised by a ballast **with a capacitor** in series. This will surely destroy components.
A good neutral is essential.
Moreover, when the neutral is interrupted and the loads on the phases are not completely balanced (i.e. the same wattage), then the voltage across the smallest load will increase and much more power will be consumed by that load. This will surely damage lamps and/or ballasts (see Fig. 119).
Suppose there are five loads of 1000 Ω, one connected between L1 and neutral and four connected between L2 and neutral. The current from L1 will be 230/1000 = 0.23 A and the power in the load will be 230 . 0.23 = 53 W.
The current from L2 will be four times higher (0.92 A) and the power too: 212 W.
If the neutral is interrupted, the phase-phase voltage of 400 V will result in a current which can be calculated from the resistances: 1000 Ω in series with 4 times 1000 Ω parallel.

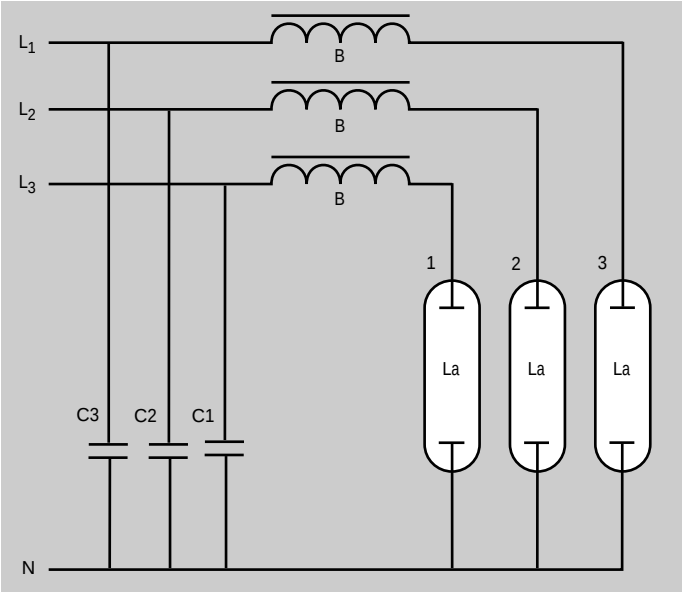


Fig. 118. Compensation in a phase/neutral network.

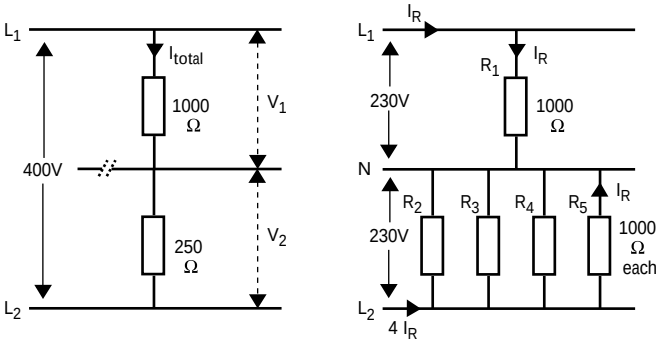


Fig. 119. The consequences of interrupted neutral in a phase/neutral network.

This makes 1000 + 250 = 1250 Ω. So the current will be 400 / 1250 = 0.32 A.
The voltage across R1 will be 0.32 . 1000 = 320 V (V = I . R), so the power in R1 will be 320 . 0.32 = 102 W.
The voltage across the four parallel resistors is 0.32 . 250 = 80 V, so the power in each resistor is 80 . 0.08 = 6.4 W.

Now it is seen that the smaller load (R1) is overloaded by a higher voltage (320 instead of 230 V) **and** a higher current (0.32 A instead of 0.23 A). The higher load (R2 to R5) is greatly underloaded.

In practice the circuits are not that simple, but the essential aspect is that in case of a floating neutral the smallest load will receive a higher voltage and a higher current and so will be overloaded.

A second possibility of resonance has to do with the employment of inductive and capacitive circuits in the same installation. In the capacitive circuit, the impedance of the capacitor is twice the impedance of the inductive ballast. So when an inductive and a capacitive circuit get in series, the total impedance will be zero, resulting in an unlimited current (resonance). This can happen in a delta-network when one phase is interrupted (Fig. 120) or in a star-network with common neutral when the neutral is interrupted (Fig. 121).
Resonance problems can be prevented with special switch gear. If the neutral in a star-network or a phase in the delta-network fails, such special gear switches off the overall supply for the lighting installation.

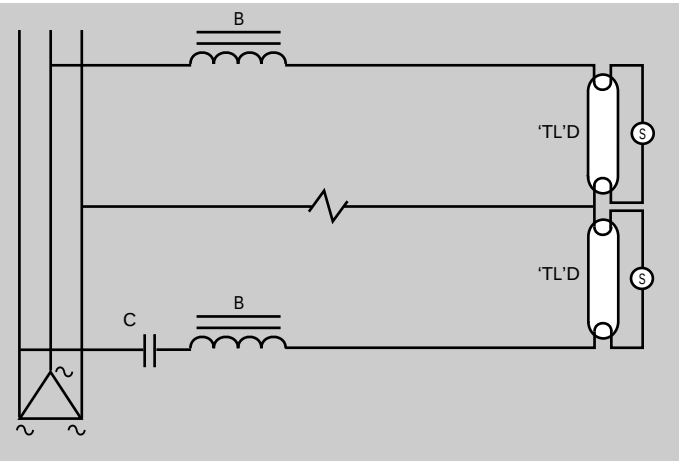


Fig. 120. Resonance in a delta-network.

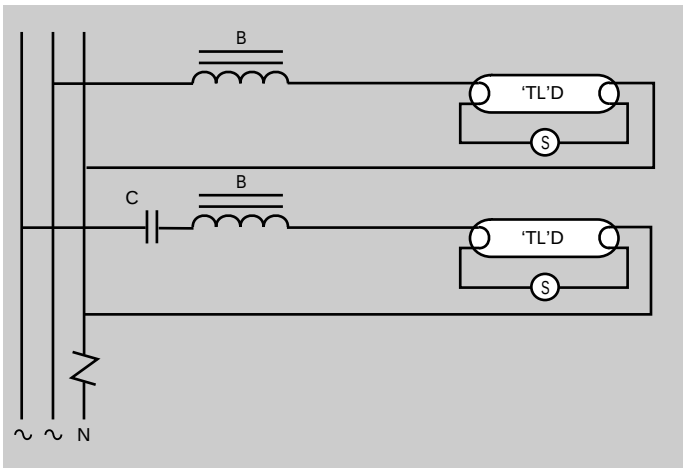
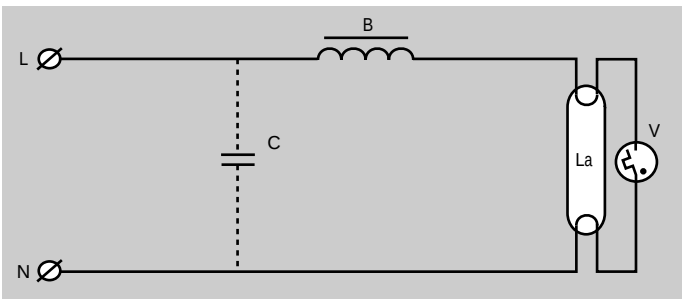
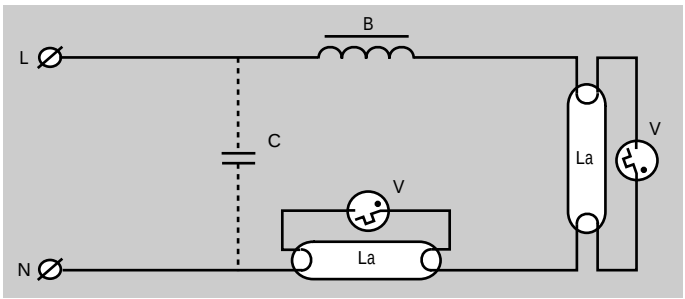


Fig. 121. Resonance in a star-network.

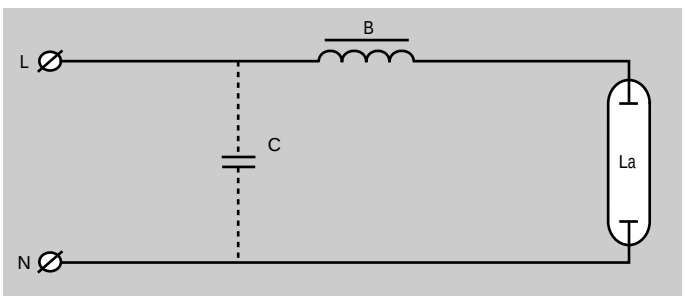
3.7 Electrical diagrams



1) One lamp, inductive or compensated with electronic or glow-switch starter 'TL', 'TL'D, 'TL'E, 'TL'U, PL-L, PL-T, PL-T(S)(C) 4-pins

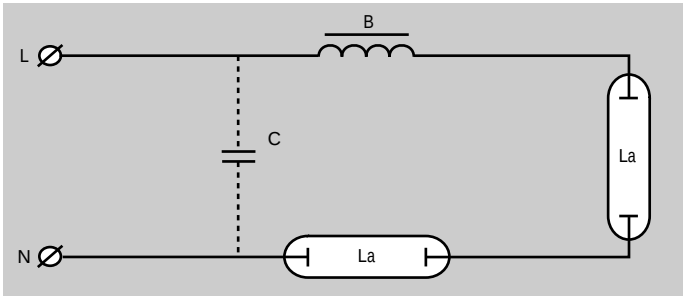


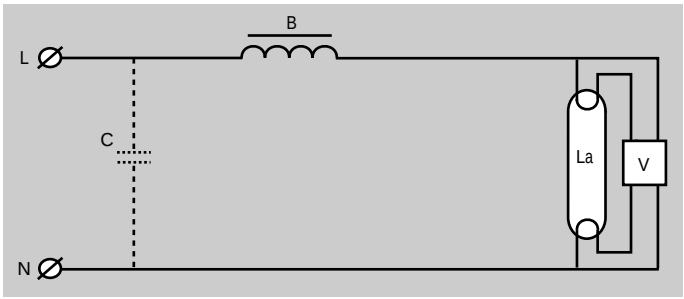
2) Two lamps, inductive or compensated with electronic or glow-switch starter 'TL', 'TL'D, PL-L

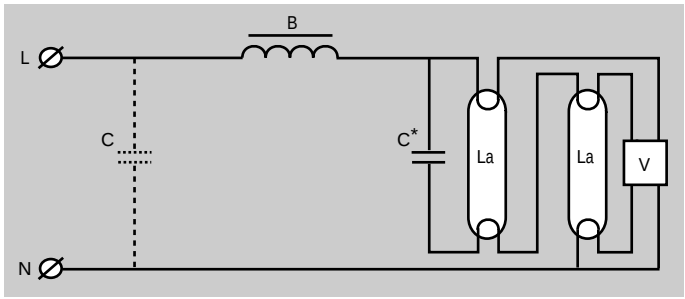


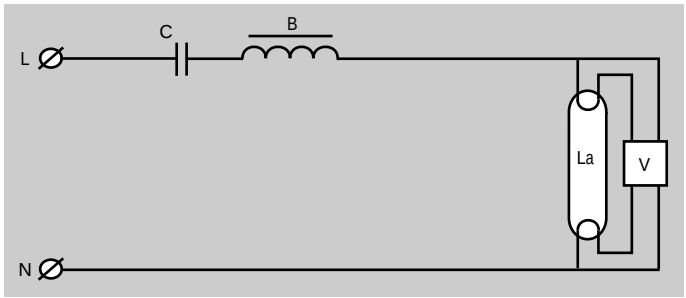
3) One lamp, inductive or compensated without starter PL-S, PL-C, PL-T (starter incorporated)

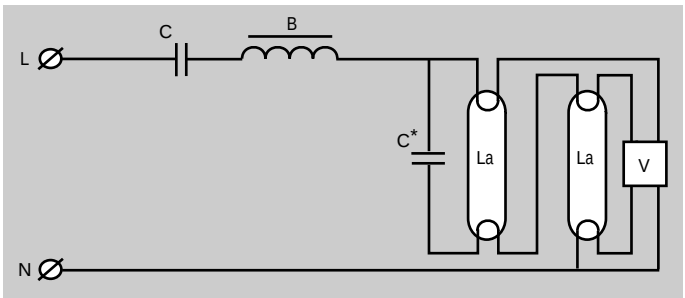
4) Two lamps, inductive or compensated without starter
PL-S, PL-C (starter incorporated)



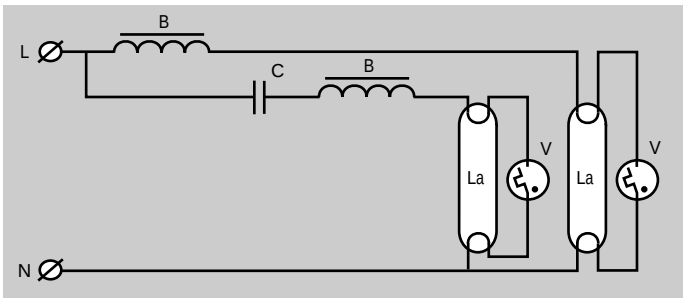




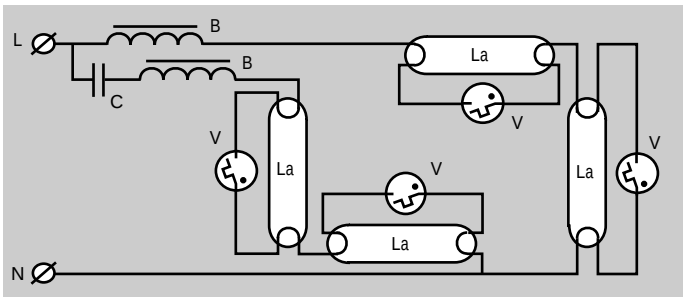




5) One or two lamps, inductive, capacitive or compensated with electronic starter ES08; 'TL', 'TL'D
The capacitor C must be of the X2 type 100 nF/250 V*



6) Duo-circuit, two lamps, with electronic or glow-switch starter 'TL'D, 'TL'E, 'TL'U, PL-L



7) Duo-circuit, four lamps, with electronic or glow-switch starter 'TL'D, PL-L

3.8 *Mains voltage interruptions and short-circuiting*

For various reasons, the supply voltage can be subject to deviations; therefore a certain degree of deviation from the rated value has been taken into account everywhere. With gas-discharge lamps deviations of up to +/- 10 per cent of the rated supply voltage normally have no detrimental effects.

Apart from such 'normal' variations, in practice three possible uncontrolled effects can be distinguished:
1) Short-circuit of the mains voltage.
2) A dip in the power supply voltage.
3) Interruption in the power supply current.
These phenomena can occur during a thunderstorm, when switching from one power supply source to another or when connecting heavy loads to the mains, and are usually of very short duration. This is a good thing too, since a single dip of 10 milliseconds (half a cycle) or even less, can have a significant influence: the lamp will extinguish. As the fluorescent lamp re-ignites in only a few seconds or even less, these phenomena hardly give problems in practice (see also section 4.1.14: Effects of mains voltage fluctuations).

3.9 *Harmonic distortion*

All gas-discharge lamps stabilised by copper/iron ballasts have harmonics in the lamp current. The first reason for this is that the lamp voltage (= the voltage across the discharge tube) is more or less a square wave of changing polarity every half cycle (see Fig. 122).
This is graphically represented as a square wave voltage, made up by Fourier analysis as the fundamental sine-wave of the mains supply and a large number of odd harmonics (see Fig. 123).
The voltage across the ballast is the vectorial difference between the supply voltage and the lamp voltage, so the harmonics of the lamp appear in the ballast voltage. As the ballast determines the current, there will be only odd harmonics in the lamp current. Even harmonics are not present.

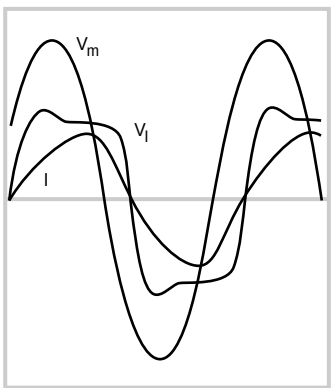


Fig. 122. Square wave form of lamp voltage.

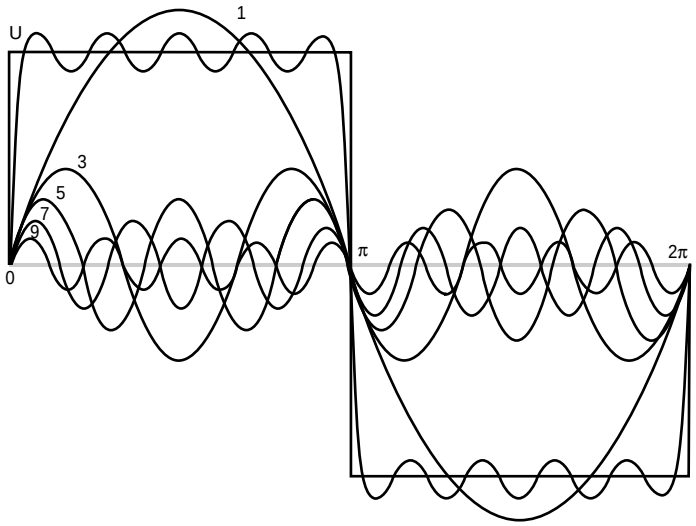


Fig. 123. Lamp voltage wave form constructed by the odd harmonics from one to nine, according to the formula:
$f(t) = 4U/\pi(\sin\omega t + 1/3\sin 3\omega t + 1/5\sin 5\omega t + ...)$.

The second reason for the presence of harmonics in the lamp current is the hysteresis of the ballast coil. With the aid of the relationship between ballast voltage and ballast current (B-H curve of the ballast coil, see Fig. 124), the resulting current can be found for any ballast voltage. Even with a pure sine-wave ballast voltage there will be some harmonics in the ballast current, but this effect is small, compared with the harmonics caused by the lamp.
The impedance of the coil becomes higher for higher frequencies, so in practice only odd harmonics up to the seventh are of any importance for the lamp current.
Practical values in percentage of the fundamental for most inductively stabilised discharge lamps are:

fundamental:	100 %
third harmonic:	10 %
fifth harmonic:	3 %
seventh harmonic:	2 %
ninth and higher harmonics:	1 % or lower

When the supply voltage contains harmonics, these values can change somewhat, but the ballast coil prevents dramatic increases.

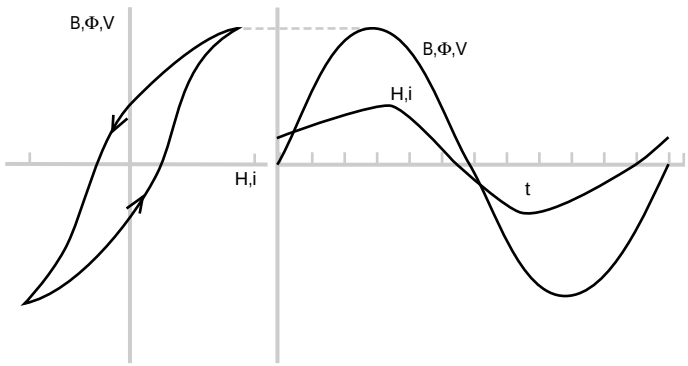


Fig. 124. Hysteresis curve of a typical copper-iron ballast.

International requirements have been made for the proportion of the harmonics in supply mains currents. According to EN 60921, for lighting equipment having an input power >25 W the maximum percentage of harmonics for the input current are:

second harmonic: 5 %
third harmonic: 30 . P.F. %, where P.F. = power factor of the circuit
fifth harmonic: 7 %
seventh harmonic: 4 %
ninth harmonic: 3 %

All Philips inductive compensated lighting circuits (P.F. = 0.5) comply with this standard. The capacitive branch of a duo-circuit has higher values, but as a whole the duo-circuit meets this standard.

To obtain a good power factor (0.9) of the system with gas-discharge lamps, mostly parallel capacitors are used. In that case the **effective** mains current will be nearly half, so the **percentage** harmonics automatically will be doubled.
Again, there will be no problems in fulfilling the requirements.
A capacitor, however, has lower impedance for higher frequencies and therefore the capacitor current is very sensitive to harmonics in the **supply voltage**.
The quality of the supply source influences the amount of higher harmonics in the mains voltage and consequently in the mains current.
The lamp is only responsible for roughly 20 per cent third harmonics in the current of the phase-conductor. When the amount of seventh or higher harmonics is too high, a solution could be found in connecting filter coils in series with the capacitors.
But adding the filter coils will result in higher third and fifth harmonics, because the total impedance for the combination of capacitor and filter coil is lower for these frequencies than the impedance of only the capacitor (see Fig. 108 in section 5.3.3). So a filter coil does not help to suppress third and fifth harmonics.

The presence of harmonics has consequences for the mains wiring. For the various wiring diagrams, calculations of the currents and harmonics can be made. In particular lighting installations connected to three-phase supplies, having a common neutral conductor, need attention.
The neutral conductor carries a current equal to the vector sum of the currents through the three phase conductors.
In a well-balanced system (equal effective phase-currents) the fundamental frequencies of these currents add up to zero, but the third, ninth and fifteenth harmonics are in phase and thus amplify each other (see Fig. 125).
The neutral therefore will carry at least about 3 . 20 = 60 per cent of the phase current. For that reason the neutral conductor must have the same cross-section as each of the phase conductors.
In case of a poorly designed system, the current of the neutral can be higher than one of the phase currents.
Also in case of a supply voltage containing some distortion, the current through the neutral can grow rapidly due to higher capacitor currents. This can be of great importance when the supply voltage is coming from a separate generator.

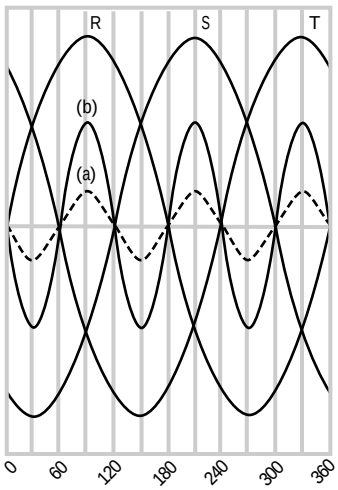


Fig. 125. Fundamental and third harmonic in a three-phase mains. R, S and T are the fundamentals in the three conductors. Owing to the phase shift, this results in a zero current in the neutral lead.
a) Third harmonic of a phase,
b) Third harmonic of all three phases in the neutral lead. The individual currents reinforce each other.

3.10 *Electromagnetic interference*

Discharge lamps do not only emit visible radiation, they also generate radio-frequency energy in the radio spectrum. This can cause disturbance of the operation of electronic equipment such as computer keyboards, television or radio receivers, hence the name **radio interference**.
As the luminaires in which the lamps are used should fulfil international requirements such as EN 55015 (CISPR 15), the radio interference in practice is sufficiently low to have no harmful effects on the surrounding. Products with the mark ⊛ conform to VDE 875 part 1.
The generation of radio-interference radiation is normally caused by lamp electrode oscillations. It has a broad-band character, usually with frequencies of up to 1500 kHz, so FM and television receivers are not affected.
The electromagnetic waves, which can have effects on the AM broadcast band, are propagated in two ways: either directly through the mains into the receiver, or via radiation picked up by the aerial.
The latter form of interference will seldom occur with discharge lamps, as the ballast will suppress the broad-band signals. The radiation produced by the lamp will nearly always remain below the threshold value at which interference takes place, especially where the lamp is at some distance from the aerial (more than, say, 1 metre).
The supply cables can emit interference radiation when they are not buried in the ground or laid in earthed steel piping, which is the best screening against interference. However, it sometimes happens that an interference signal reaches the receiver by way of its mains input. The interference signal can consist of high-frequency harmonics of the mains frequency or high amplitude pulses. The former are generally adequately suppressed in the ballast. Experience has shown that interference may be caused by fluorescent luminaires with external ballast where the radiation from the supply wires is picked up by telephone or other cables. If external ballasts are used, the supply cables between ballast and luminaire should be as short as possible. Ballast coils should be split into two adjacent parts (split-windings type of ballast). In case of Class I luminaires the supply wires should be shielded and this shielding should be properly connected to the earth connection.
In practically all other cases it will be necessary to connect a delta filter between the mains supply and the input to the lamp circuit.

Fig. 126 shows an example of a delta filter used for suppressing radio interference. The apex of the filter must be connected to the ground. More complicated filters are used in three-phase networks.

Avoid earth looping (all earth terminals to one point) and create maximum distance between audio and lighting cabling. If audio and lighting cables have to cross each other, it should be done in a perpendicular way. In sensitive applications screening of cabling is necessary.

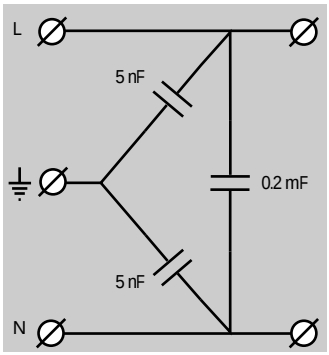


Fig. 126. Delta filter used for suppressing radio interference.

3.11 *Lifetime*

When used within the specifications, the various circuit components will last for many years with no more failures than approx. 1 per cent per year (except lamps and glow-switch starters).
Most of the time, failures in the gear components are caused by external circumstances, such as wrong wiring or connections, short-circuiting, extreme heat or humidity, mains voltage peaks, poor maintenance and the like.
For example, capacitors for lighting installations with the VDE approval according to VDE 0560 must achieve a lifetime of 30 000 hours at their marked voltage (250 or 450 V) and their maximum case temperature (85 or 100 ºC). Higher voltages will shorten the capacitor life as follows:

Voltage (times V_{mark})	1.15	1.25	1.30	1.35	1.40	1.45	1.50
Lifetime (h)	8500	4000	2900	2000	1500	1100	780

A failure rate of 5 per cent is then accepted and the capacitance loss must be less than 10 per cent for parallel and 5 per cent for series capacitors.
Temperatures above the marked maximum capacitor case temperature will halve the lifetime of the capacitor for every 8 degrees increase.
Therefore, if there are too many failures with capacitors, the capacitors may be too hot or the applied voltage is (temporarily) too high.

For glow-switch starters the number of switches is specified as 10 000 or more. Deviations are caused by the different starting currents of the various lamp types.
For electronic starters, the most relevant factor is the allowed ambient temperature or the maximum case temperature t_c.
The specified temperature range is from -40 ºC till + 80 ºC. Exceeding these temperature limits will shorten the lifetime dramatically.

3.12 *Ambient and operating temperatures*

Temperature is of prime importance for the proper functioning of discharge lamps (Fig. 127a/b). In general, fluorescent lamps are very sensitive to changes in the ambient temperature (see section 3.6: Effects of temperature).

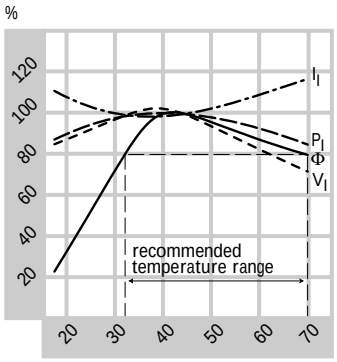


Fig. 127a. Relative values of luminous flux (Φ), lamp voltage (V_l), lamp current (I_l) and lamp wattage (P_l) as a function of lamp head temperature, for a PL lamp.

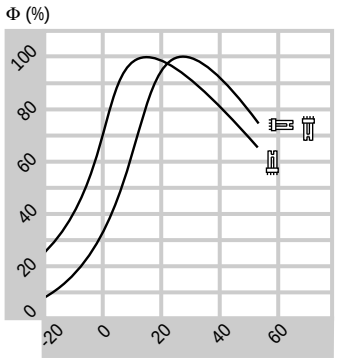


Fig. 127b. Relative values of luminous flux (Φ) as a function of the ambient temperature and the burning position (PL lamp).

For the total system the ambient temperature also is of great importance, due to the fact that certain minimum and maximum operating temperatures are specified for the various components.

Minimum temperatures

1) Lamps

Supplied with the nominal voltage, fluorescent lamps will start quite normally at temperatures down to approx. -20 ºC. The minimum allowed temperature depends on lamp type and starting system, which determines the maximum ignition time (ranging from 2 to 20 seconds). Also the circuitry (leading or lagging) has influence on the ignition process. Two lamps in series normally ignite less easily than the one lamp circuitry. In the lamp data sheets the minimum temperature and the resulting ignition time can be found for the various circuits. Below these specified temperatures smooth ignition cannot be guaranteed.
In the table below, the ignition time of a PL-L 24 W lamp (in sec) is given as a function of lagging or leading circuitry, nominal or sub-nominal supply voltage, type of starter and ambient temperature.

Circuit	Lagging				Leading			
Voltage	Nominal		Nominal -8%		Nominal		Nominal -8%	
Starter	S10	ES08	S10	ES08	S10	ES08	S10	ES08
Ambient temp. ºC								
-30	10	2	*	2	*	*	*	*
-25	7	2	*	2	20	2	*	2
-20	6	2	12	2	8	2	15	2
-15	6	2	12	2	8	2	15	2
-10	6	2	10	2	7	2	14	2
-5	6	2	10	2	7	2	11	2
0	6	2	10	2	7	2	11	2
+5	6	2	9	2	6	2	8	2

* Proper ignition not guaranteed.

Once ignited, the lamp warms up its surroundings and, after run-up, the low ambient temperature has less influence on the electrical performance. Still, the light output varies with the actual tube wall temperature. Capacitive circuits give less light at low temperatures than inductive circuits due to the constant-current characteristic of the capacitive circuit.

2) Gear

The minimum temperature for some electronic components and for compensating capacitors is -25 ºC. The capacitance of capacitors, for instance, declines steeply below that temperature. For that reason gear should be installed at places where the ambient temperature will not fall below -25 ºC.

3) Luminaires

In general the construction of the luminaires and optics is not affected by low ambient temperatures down to -25 ºC. Of course plastic parts such as clips are more brittle at low temperatures and should then be handled with care.

Maximum temperatures

1) Lamps

For fluorescent lamps the temperature of the glass tube wall is of prime importance, especially with regard to the applied phosphors. It will be clear that the actual lamp temperature very much depends on the luminaire in which the lamps are placed. Lamps must only be used in luminaires which are constructed for that particular type of lamp. For some lamp types absolute maximum temperatures of a specified spot are given (see SL, Fig. 128). With this in mind, also see maximum and ambient temperatures under point 3) Luminaires.

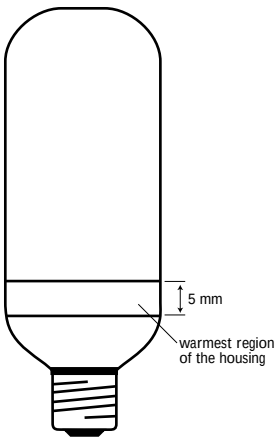


Fig. 128. The maximum recommended ambient temperature at which an SL lamp can operate is 55 ºC. The part of the lamp with the highest temperature is a 5 mm wide section around the circumference of the housing. The temperature measured in this region, on the surface of the housing, is about 150 ºC. Exceeding this temperature can result in reduction of lamp life.

2) Gear

a) Ballasts

The main ballast temperature parameters t_w (maximum permissible coil temperature) and Δt (coil temperature rise in standard test) are described in section 5.1.6. Ballasts are normally mounted directly inside a luminaire. The actual ballast coil temperature in practice depends on the cooling properties of the ballast surroundings, e.g. material of mounting surface, type of fixing, standing air or ventilation. For that reason it is impossible to predict the actual ballast coil temperature without doing a temperature test in practical circumstances. Of course a ballast normally will be cooler when it has lower losses and/or a lower Δt value and/or larger dimensions.
Connections to a ballast are in many cases made by means of a terminal block. These terminal blocks have their own temperature limits, usually 100 to 120 ºC, which should not be exceeded.

b) Starters

Since they incorporate semi-conductors and capacitors, electronic starters have a maximum permissible temperature. This value is marked on the starter and is usually 80 or 90 ºC. In most applications the starter case temperature will not exceed this limit, as the starters hardly produce heat by themselves.
But if the starter is incorporated in the luminaire or placed near the hot ballast, its temperature can rise considerably. It is advisable to mount the starter on the coolest spot possible.

c) Capacitors

Capacitors have a maximum permissible temperature, which is marked on the case and is usually 85 or 100 ºC. Above this temperature they can break down or lose capacitance. They hardly produce heat by themselves and must be placed away from the hot ballast. Additional temperature measures are advisable when the capacitor case temperature is unknown and can be critical.

3) Luminaires

Professional luminaires are, like ballasts, designed and constructed to have (under standard conditions) an average lifetime of at least 10 years in continuous operation with the appropriate (maximum) lamp type. The volume of the luminaire, the choice of materials, the cooling properties, etc., are chosen in such a way that, at an ambient temperature of 25 ºC in indoor applications, no part of the luminaire exceeds its maximum specified temperature. In practice this ambient temperature limit is sufficient to cope with most applications and non-nominal circumstances, as long as the latter are within the specifications. In cases where the ambient temperature is (temporarily) higher than 30 ºC, the most critical part of the luminaire may exceed its maximum specified temperature. This, of course, shortens lifetime, but to what extent is in general hard to say. It depends on the part in question (e.g. luminaire housing, mirror optics, cabling, lamp tube, lamp base, etc.).

In outdoor applications a natural air circulation around the luminaire is assumed, which gives a cooling effect of about 10 ºC. The same luminaire with an indoor ambient temperature limit of 25 ºC, will in practice have an outdoor ambient temperature limit of 35 ºC. If for outdoor luminaires an ambient temperature t_a is given, it refers to the outdoor situation.

Special lamps, luminaires and electrical circuits have been developed for use in hot, cold, humid or potentially explosive environments. Amalgam lamps - and to a lesser extent also krypton-filled ('TL'D) lamps - are not susceptible to the drop in light output at high ambient temperatures experienced by normal fluorescents. When normal lamps are operated on inductive ballasts, these may well overheat due to the increase in the lamp current brought by the higher operating temperature (see Fig. 129).
However, where the decrease in light output and luminous efficacy can be tolerated, and provided proper measures are taken to prevent overheating of the circuitry, tube wall temperatures of up to about 90 ºC are acceptable.
The use of properly ventilated luminaires will, in most environments, obviate any heat problems. An air stream through the luminaire is an effective way of removing the heat generated by the lamp and ballast.

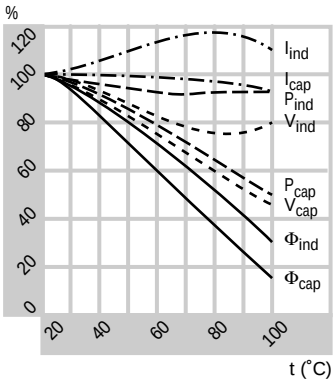


Fig. 129. Influence of temperature increase on lamp current (I), lamp voltage (V), lamp power (P) and luminous flux (Φ) for a 40 W fluorescent lamp on inductive and capacitive ballasts.

3.13 *Effects of mains voltage fluctuations*

The lamp voltage of a fluorescent lamp mainly depends on the lamp construction (length and diameter) and the gas filling. It hardly changes as a consequence of voltage variations in the mains, which means that fluctuations of the mains supply must be compensated for by the ballast. An increasing mains voltage results in a higher ballast current, as the impedance of the ballast is nearly constant (see section 5.1.2: Stabilisation). As the ballast current equals the lamp current, the power in the lamp and so the light output of the lamp increases at rising mains voltage.
Supplies with wide mains voltage deviations will lead to considerable deviations in luminous flux. Deviations of less than 5 per cent in conjunction with the normal ballast will keep the values within acceptable limits. The lumen level will not show fluctuations of more than 10 per cent. When the mains voltage constantly differs more than 5 per cent from the ballast rated voltage, the appropriate ballast should be applied.

Due to the constant-current characteristic of the capacitive circuit, the influence of mains voltage deviations is less than with the inductive circuit (see Fig. 130).

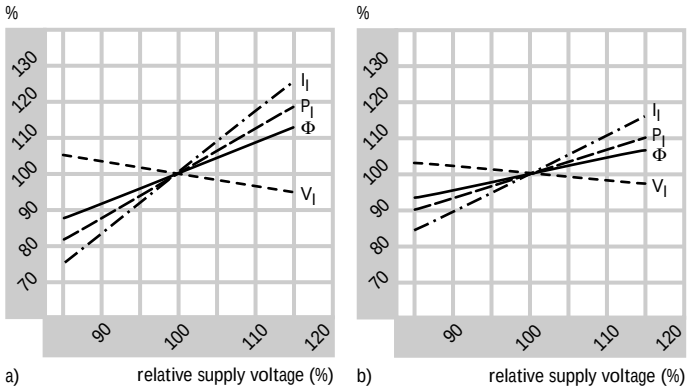


Fig. 130. Influence of variation of the supply voltage on a PL-L 18 or 24 W lamp operated in a lagging (inductive) circuit (Fig. 130a) and in a leading (capacitive) circuit (Fig. 130b). Relative values of luminous flux (Φ), lamp current (I_l), lamp wattage (P_l) and lamp voltage (V_l). Ambient temperature: 25 ºC, burning position: base up.

3.14 *Electrical wiring*

The electrical wiring in a luminaire must be such as to ensure its electrical safety. This necessitates great care both in the choice of wire used and in its manner of installation.
There are a great many different types of wire available, in both single-core (solid) and multi-core (stranded) versions (Fig. 131). There is a wide variety in wire materials and diameters, as well as in thickness and quality of insulating cladding material.

Fig. 131. Types of wire used in luminaires. From left to right: solid core (3), stranded (3), with heat-resistant insulation (3) and high-voltage ignition cable (1).

Whether the wire is single-core or stranded makes no difference as far as its electrical characteristics are concerned. Mechanically, however, things are quite different.
Single-core wire is much stiffer than stranded wire, which means that fewer cable fasteners are needed to hold it in position. It is also easier to strip, after which it can be pushed into self-clamping connector blocks without further preparation. It is therefore more suitable than stranded wire for the internal wiring in a luminaire (Fig. 132).
Single-core wire is, however, not suited for use in luminaires that are subjected to vibrations and shock. The vibrations can be transmitted along the wire, causing fixing screws to be loosened or the wire to fracture and break. Here, stranded wire must be used. Being more flexible, it is able to absorb vibrations harmlessly. Stranded wire is also necessary in those situations where the wire must be able to bend in use - as in a spotlight, for example (Fig. 133).

Fig. 132. Solid-core wire inside a luminaire for fluorescent lamps. White wires are used where the wiring is visible from below.

The diameter (or rather the cross-sectional area) of the wire must be matched to the strength of the current flowing through it. A wire whose area is too small has a resistance that is too high and it will become warm, the resulting heat loss reducing the efficiency of the luminaire. A minimum nominal cross-sectional area of 0.5 mm^2 is laid down in IEC 598, although this may be reduced to 0.4 mm^2 in certain cases where space for internal wiring is severely restricted (see IEC 598, section 5.3.1).

Of particular importance with regard to insulation material and thickness is, of course, its temperature resistance. Here it must be borne in mind that it is not only the temperature of the air in the luminaire that matters, but also that of components with which the insulation may come in contact, such as ballast and lampholders. The insulation of the wire used must be resistant to all such temperatures, not only under normal conditions of operation, but also in the presence of a fault condition.
Not all sorts of insulation are suitable for use in luminaires. For example, simple PVC (polyvinyl chloride) insulation is only heat-resistant up to 90 ºC. It contains a softener, which can vaporise, making the insulation brittle and therefore prone to damage. Moreover, the evaporated softening agent attacks a number of plastics used in the manufacture of luminaire housings. There is, however, an inexpensive PVC insulation that is heat-resistant up to a temperature of 105 ºC, and which is safe in this respect. Where temperatures in excess of 105 ºC can arise, yet another kind of PVC insulation is usually employed, one that is resistant up to 115 ºC.

Where still higher temperatures may be encountered, as in floodlights for example, siliconerubber (170 ºC to 200 ºC) and PTFE (polytetrafluorothene) (250 ºC) insulating materials are available. Extra

Fig. 133. Flexible stranded wire inside the pivoting base of a spotlight.

protection can be obtained by covering the insulation with a glass-fibre sleeve.
In order to keep the chances of heat damage to the insulation to a minimum, the wiring run is so chosen as to avoid as far as possible any 'hot spots' in the luminaire, such as ballast or lampholders.
The cable fasteners used to hold the wiring in place should allow it some slight freedom of movement, for the insulating covering of wire that is under mechanical strain will have a lower heat resistance than that specified by the manufacturer.

There is an internationally standardised colour coding for electrical wiring, namely that specified by the IEC: brown for live, blue for neutral and yellow/green for earth.
The only time when a departure from this colour coding is permissible, is in the case where luminaires have internal wiring that is visible when the unit is in use. A white insulation is then often used so as to blend in with the white of the housing. The proviso here is that the connection block is clearly labelled.

3.15 *Hum*

In general, lamps, ignitors, capacitors and even luminaires do not produce any disturbing noise level when correctly used in their application. Sometimes during the starting process some hum or rustling can be noticed, especially with glow-switch starters. If hum is noticeable, it almost always comes from the ballasts. Anyhow, when used in indoor applications, e.g. shops, the hum level caused by control gear should be as low as possible.

The electric current passing through the coil of a ballast causes a magnetic field, which arranges the disorderly arranged elementary magnetic particles of the ballast iron. So we find in the iron magnetostriction and magnetic poles.
The ordering of the elementary magnets causes a certain deformation of the iron (magnetostriction), resulting in the iron expanding in certain directions. This process is repeated every half cycle if alternating current is used and results in a noise of 100 Hz and higher harmonics.
The magnetic poles exert forces of attraction in the air gap of the ballast core, also resulting in a noise of 100 Hz and higher harmonics.
The generation of these magnetic vibrations can be suppressed to a high degree by means of a suitable design of the ballast. In particular, air gap filling and ballast encapsulation can contribute to low noise levels.
But the magnetic field also spreads outside the magnetic core. All magnetic metal parts in the immediate surroundings of the ballast, such as the ballast case, the sheet-steel of the luminaire, etc., are subject to forces in this magnetic field and can cause noise.

To avoid unpleasant 'humming' noise, constructions for the ballast mounting, as well as the ballast mounting itself, must be as rigid as possible. The hum will be more pronounced if the ballast is mounted on a resonant surface. Avoid loose metal parts and create distances between ballasts and metal parts.

3.16 *Dimming*

Dimming can be defined as the reduction of the luminous flux of a lamp, either continuously or in steps, by reducing the operating current. This is not always possible without adversely affecting the performance of the lamp.

Basically, dimming is achieved in one of the following ways (see Fig. 134):
- by switching a (variable) resistor or inductive coil in series with the lamp(s),
- by running the lamp(s) from a variable transformer,
- by suppressing the AC waveform of the supply current during part of the cycle by means of an electronic element (thyristor); such a device is also called a 'chopper circuit',
- by increasing the frequency of the supply current of an inductive coil, thereby increasing the impedance of this.

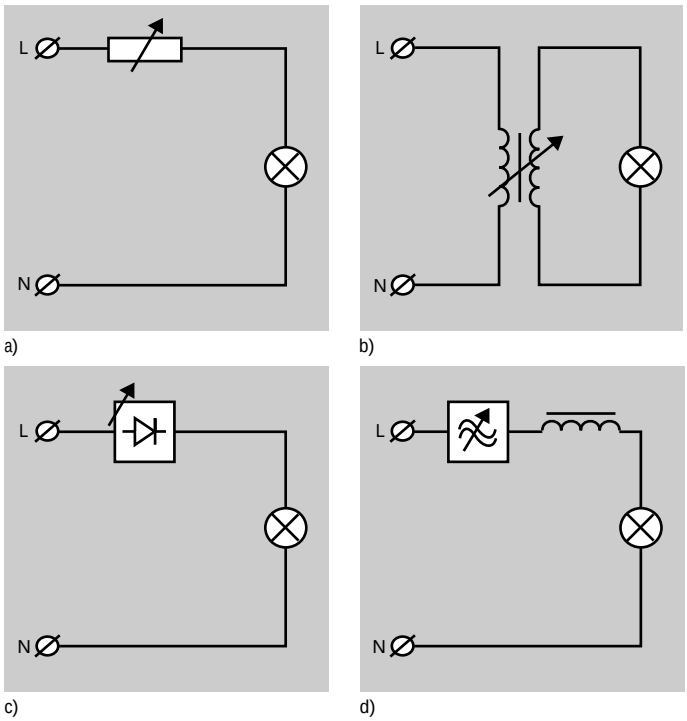


Fig. 134. Four basic ways of dimming.
a) by a variable resistor,
b) by a variable transformer,
c) by a thyristor circuit,
d) by frequency regulation.

Resistors are now rarely used for dimming purposes, because they are inefficient and produce a lot of heat.

Variable transformers are appreciated because of their high power handling capacity, but at the same time they are heavy and expensive.

In the case of fluorescent lamps operated on electromagnetic gear dimming is mostly achieved by the extra inductive coil in series or by the thyristor circuit (Fig. 135). In both cases only inductive circuits are allowed and the parallel compensating capacitor must be placed before the dimming device. Capacitive or duo-circuits are not allowed because:
- with the extra series impedance the total impedance for stabilising would become lower instead of higher,

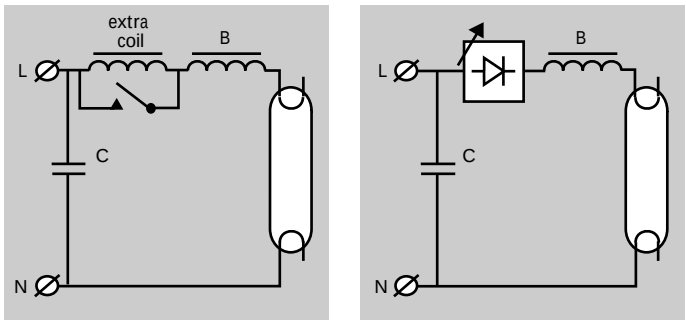


Fig. 135. Dimming with an extra inductive coil in series and by a thyristor.

- with the thyristor circuit the moment of current suppressing must be different for the inductive and the capacitive branch due to the phase shift, which is impossible to realise in one and the same device.

During dimming only the lamp current will decrease and the capacitor current will remain the same. The result is that the power factor will become capacitive and will shift to lower values.

Inductive coils, in the form of an extra ballast, are used to reduce the light output of street lanterns after a certain hour. This is done either by switching the extra ballast in series with the principal one, or by using two ballasts of half the nominal power rating in parallel, switching one off when dimming is required.

Thyristor dimmers are by far the most popular nowadays, because they are small and inexpensive.
Dimming to give half the light output is nearly always possible. By using thyristor dimmers practically any type of fluorescent lamp can be dimmed down to about 50 per cent of the nominal lamp current, which roughly corresponds to a 50 per cent reduction in light output (so-called 'top dimming'). For indoor installations, however, top dimming is of limited practical use and at ambient temperatures below 5 ºC krypton-filled lamps, like the Philips 'TL'D may become unstable when dimmed.
The disadvantage of thyristor dimming where lamp circuits incorporating glow-discharge starters are concerned, is that the dimmed lamp will cause the starter to become conductive. At what degree of dimming this will happen is difficult to predict, but the result is that the starter will make repeated attempts to ignite the lamp. This is the main reason why dimming of fluorescent lamps in a glow-switch starter circuit is discouraged.
When dimming to below 50 per cent of the nominal current, the discharge will no longer provide sufficient heat to keep the electrodes at the proper emission temperature and continuous electrode heating becomes necessary. The heating current must be independent of the lamp current, thus a separate heating transformer will be required. Lamps operated in this mode can be dimmed to give almost zero light output (but not entirely, unless a switch is provided). They can also be started from a dimmed position. These dimming installations almost invariably operate at high frequency to prevent disturbing flicker at low lighting levels.

Frequency regulation is the most recent technology, and is employed in the Philips HF electronic light regulation ballast. With this ballast the lamp current can be regulated down to about ten per cent of the nominal value. Dimming is here achieved by increasing the frequency of the supply current.

3.17 *Stroboscopic effect and striations*

For this subject, see also section Lamps, 3.10.

1. A fluorescent lamp operating on an alternating current will exhibit a fluctuating light output, because the lamp extinguishes and restrikes every half cycle of the supply. So this light ripple has a fixed (mains) frequency and can cause the stroboscopic effect. It mainly depends on the used phosphors of the lamp: the use of phosphors exhibiting little or no afterglow may result in more pronounced fluctuations.
   The use of inductive (Fig. 136a) and capacitive circuits together in a duo or 'lead-lag' combination reduces the light ripple (Fig. 136b) In an inductive circuit the lamp current will lag behind the supply voltage by approx. 60º, while in the capacitive circuit the current will be ahead of the voltage by approx. 60º. This means that the light output of a twin-lamp duo-circuit has two components mutually shifted by 120º.
   The best solution for preventing the stroboscopic effect is spreading the lighting over the three phases of the supply (Fig. 136c), where the minimum light output of one lamp coincides with high light outputs of the two other lamps.

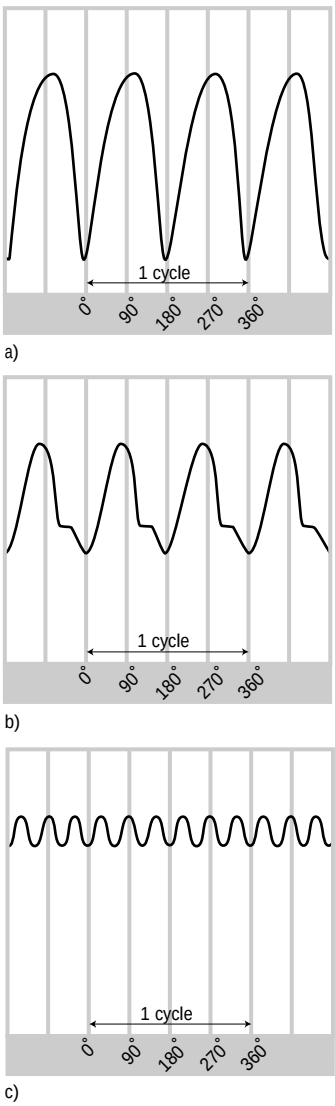


Fig. 136. Prevention of the stroboscopic effect by using combined inductive and capacitive circuits ('lead-lag' or duo-circuit) and by spreading the lighting over the three phases of the supply.

2. The light ripple can also have an effect on the quality of camera pictures. This phenomenon may become apparent when CCD colour cameras operate in auto-shutter mode and the lighting of the area is predominantly with fluorescent lamps,
The auto-shutter mode is normally selected when cameras are equipped with manual or fixed iris lenses and the automatic light response is controlled by an electronic shutter system in the camera. The more light is exposed to the camera, the shorter the shutter time. This means: the shorter the light integration in the sensor takes place. For example, with a shutter time of 1/1000th of a second the light integration of the CCD sensor is 1 msec only. Within the normal CCIR scanning period of 20 msec (50 Hz) the 1/1000th of a second the light intergration time is just a snap-shot in the normal frame scanning period. In this manner the sensitivity of the camera is reduced.
As described before, the light output of fluorescent lamps varies continuously from minimum (at zero crossing) to maximum during the positive and negative phases of the mains voltage, twice during one mains voltage cycle. In other words: the fluorescent lamp is flashing 100 times per second. Due to the lag of our eye, viewing a scene illuminated with 'TL' lamps, gives the impression of a white and continuous light output.
At the dip of the light output, the excitation of the fluorescent powders is with minimum energy. At this point, the light output is therefore not white, the colour depending on the properties of the non-saturated excitation of the fluorescent powders in the lamp. As the human eye works as an integrator, this effect cannot be noticed. The light ripple of a 'TL' lamp is illustrated in Fig. 137.
When the automatic shutter in the camera is switched off, the two light ripples of a 'TL' lamp are integrated during the normal 20 msec frame integration time of the sensor and consequently the light impression is white. This is illustrated in Fig. 138.
Using the automatic shutter in sufficiently illuminated scenes, the shutter speed increases and consequently light integration in the sensor takes place during a short period of time. Depending on the position where the light integration (snap-shot) takes place with respect to the mains phase (light ripple), it is now possible that a TV

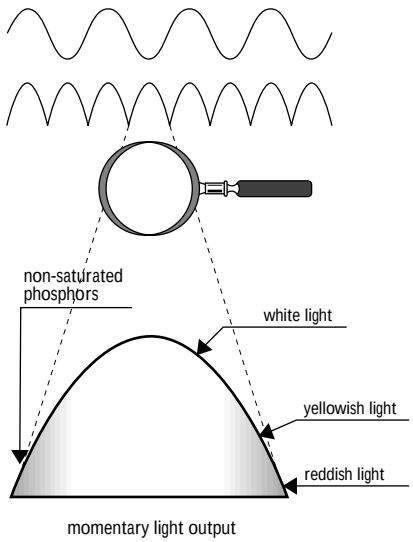


Fig. 137. Colour shift during the 100 Hz light ripple of a fluorescent lamp

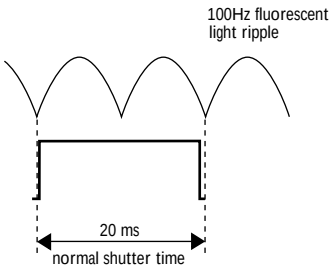


Fig. 138. The 20 msec frame integration time of a CCD colour camera with the automatic shutter switched off, compared with the 100 Hz fluorescent light ripple.

frame is shot during the non-saturated excitation of the fluorescent light, see Fig. 139.
It can be said, that the light at this point in time is not white and the light output is less. If the phase of the camera shutter remains constant with respect to the mains phase, the automatic light control and the white balance circuits in the camera will compensate for these effects and stable pictures are produced. This situation is obtained by locking the camera frame synchronisation to the mains (mains lock). When there is no fixed phase relation between the scanning frequency of the camera (free running) and the mains frequency, the camera will take a snap-shot of the scene at varying phases of the fluorescent lamp light output. This causes a colour fading to become visible. The extent of colour fading is depending on the lighting design of the area.
In applications where the scene is illuminated with just one fluoresecent lamp or other gas-discharge lamp, stabilised by conventional gear, the colour fading risk is at its maximum. It is recommended that cameras be locked to mains frequency and the phase of the camera synchronisation be adjusted such that the camera signal output is maximum. If mains lock is not possible in such an application, the lens iris should be closed to the point where the colour fading just disappears. Now the shutter speed is less (full frame integration) and the additional benefit is that the sensor smear effect is less. This solution cannot be used in applications that need short shutter speeds to suppress movement blurr.
In all other cases (combination of inductive and capacitive circuits, three-phase installation of high-frequency stabilised) this phenomenon will not occur.

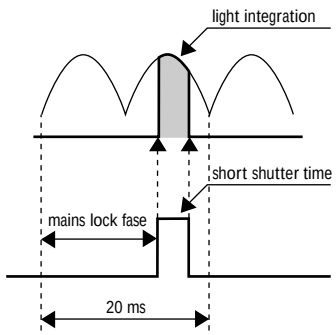


Fig. 139. Using the automatic shutter and with the camera locked to mains frequency, it is possible to shoot stable and white pictures.

3. The movement of the arc on the electrode(s) (flicker) has no fixed frequency and will only become noticeable in exceptional cases. It

depends on several factors, including lamp position, supply voltage, temperature, age of the lamp (electrode) and also of the lamp current wave form (peak factor).

4. Striations are noticeable as a pattern of more or less bright regions in the long discharge tube of fluorescent lamps. The pattern can move through the discharge tube. It can appear when the lamp is cold or when the lamp is dimmed down to too low a level.

3.18 *Circuit breakers, fusing and earth leakage*

1 Standard conditions

Under normal conditions the highest current which can occur is the current during the starting phase. When the starter is closed, practically the entire supply voltage is across the ballast, resulting in a high current and a low power factor. The fuses must be capable of handling this high initial current for several minutes. For most of the fluorescent lamps stabilised with copper/iron ballasts, this starting current is about 1.5 times the normal operating current.

During switching on, a few other processes are going on as well:
- the (empty) parallel compensating capacitor will be charged with a high inrush current,
- depending on the magnetic saturation of the ballast a voltage induction will take place in the ballast,
- gas-discharge lamps can have some rectification or DC component in the lamp current.

These phenomena occur in the very first 3 to 5 milliseconds and can result in a peak current of 15 to 25 times the nominal current. This surge current will depend on the lamp and ballast type and the number of lamps per circuit as well as, of course, on the resistance and impedance of the lamp and supply cables and the impedance of the mains supply network. This latter part varies greatly in practice. It is recommended that a surge current of 20 to 25 times the nominal current during the first 3 milliseconds be used and 7 times the nominal current for the first 2 seconds for parallel compensated circuits as a guide for selecting fuse ratings.
In the duo-circuit the capacitor is connected in series with the coil, so the very high surge currents cannot appear in this case.

Devices for switching and fusing must be capable of handling these currents correctly. This means that for fuses slow-acting gl types (normal general purpose type for cable fusing) have to be used (German name: gL). The main purpose of the fuse is to protect the cable and the distribution part of the lighting installation from damage in case of a failure in the installation. So the fuse rating is primarily related to the cable core used in the installation.
As the various national electrical safety rules differ slightly, the recommended fuse ratings for lighting equipment published by the various lamp, gear and fuse suppliers are not always the same. Moreover, there are differences in the various brands of fuses.
As a guide, it is recommended to load gl-fuses to not more than 50 - 70 per cent of their rating.

The same applies to main circuit breakers (MCB's). Although the switching characteristics of MCB types are laid down in recommendations like CEE-19-2nd edition, the various characteristics of different types and brands can differ considerably.
Circuit breakers are tested and calibrated to carry 100 per cent of their rated current in open air at a specified temperature, normally 25 ºC. When mounted in an enclosure, the ambient temperature may be higher. As a result, circuit breakers are permitted continuously to carry only 80 per cent of their current rating. The manufacturer's technical information should be carefully reviewed to determine the exact capabilities of a specific breaker.
Main circuit breakers work on two principles:

1) The thermal part, being a bi-metal strip, which is heated by the passing current. The switching-off characteristic is similar to that of a fuse and is influenced by time and current value. It is effective after approx. minimum 2 to 5 seconds for the smaller overload currents.
2) The electromagnetic part, being a magnet coil, which is effective for the high overload currents and reacts within milliseconds (see Fig. 140).

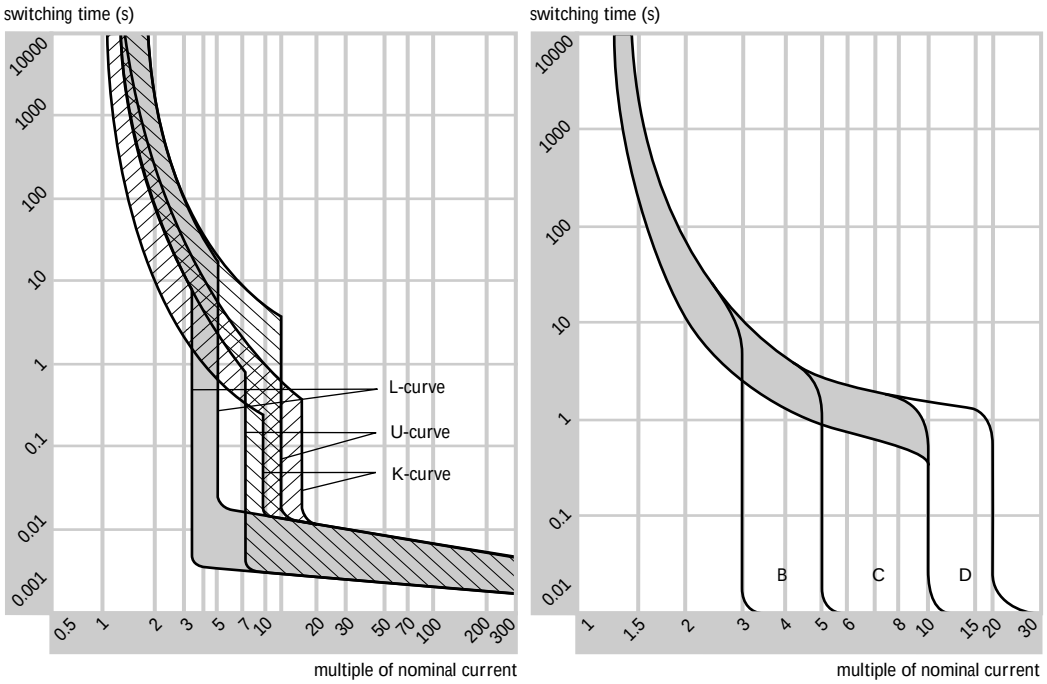


Fig. 140. Switching characteristics of various types of main circuit breakers.

According to CEE-19-2nd edition (L, U and K)

According to EN 60898 / VDE 0641 (B, C and D)

For lighting applications the less sensitive types of circuit breakers are advised, such as the U-, K-, C- or D types.
Taking the 10 A MCB type C as a reference (with a load assumed to be 1), then the other types can handle loads as shown in the following table:

C-type		B-type		L-type		U-type		K-type	
10 A	16 A	10 A	16 A	10 A	16 A	10 A	16 A	10 A	16 A
1	1.6	0.6	1	0.7	1.1	1.3	2.1	1.5	2.5

Information on what lighting load a certain MCB can handle may be given by the MCB supplier, provided information about the cabling lay-out, lamp type and circuit is available. As a guide, a practical value for the figure (1) of the 10 A MCB type C represents 1500 W lighting load with the conventional gear.

2 Non-standard conditions

A fluorescent lamp circuit normally consists of four parts: lamp, ballast, starter and compensating capacitor.
The effects of short-circuiting one of these parts are:

1) Short-circuiting of the lamp

This has been described above: in the inductive circuit the mains current will be approx. 1.5 times the nominal value, which means an extra temperature rise of the ballast and cabling by a factor 1.5^2. There is no immediate damage or danger and the situation can continue to exist for days. Tested in a complete luminaire at 110 % V_{mains} the ballast temperature must be lower than 232 ºC, which guarantees a minimum lifetime of the ballast of 20 days in this situation. In most cases the mains fuse will not blow and the situation can only be solved by good maintenance.
In a capacitive circuit the current is even lower than the nominal value when the lamp is short-circuited. So then the described effects are not noticeable.

2) Short-circuiting of the ballast

As there is no current limit in this case, the lamp current will rise immediately to an undefined high value in the inductive circuit. If the current is not switched off by the mains fuse, the lamp will normally become an open circuit because (one of) the lamp electrodes will melt. In most cases this process is so quick that there will be no extra danger or damage. In practice, however, it happens that the ballast is partly short-circuited inside the copper coil, for example at the end of the ballast lifetime. This results in a higher ballast temperature and a higher lamp power. This process is cumulative and normally the mains fuse will not blow, while the ballast gets hotter and hotter until a fatal earth or winding breakdown occurs. For this reason, the ballast must be mounted in such a way that it can cause no danger during end-of-life failure.
Good maintenance can prevent blown-up lamps and burned-out ballasts.
When in a capacitive circuit the ballast is short-circuited, the lamp is only stabilised by the series capacitor. In most cases the lamp will extinguish, as the remaining impedance is too high ($|Z_c| = 2.|Z_L|$).
In those cases where the lamp continues to work, the high capacitive peak currents through the lamp, will rapidly damage the lamp electrodes. The lamp will blacken at the lamp ends and sooner or later a lamp electrode will break, resulting in an open circuit.

3) Short-circuiting of the ignitor

At the end of the lifetime of a glow-switch starter the bimetal electrodes will stick together and will not re-open again. Then the short-circuit current will continuously flow through the lamp electrodes, resulting in strong lamp end blackening and a hot ballast. This effect often can be found in practice if the maintenance of the installation is not well done. It is advisable to renew also the glow-switch starter at lamp replacement.

4) Short-circuiting of the parallel compensating capacitor

This results in a complete short-circuit of the mains, so the mains fuse will react. In fact, short-circuiting of the capacitor will not occur in practice as capacitors for lighting applications must have a switch-off mechanism that results in an open circuit during excessive capacitor currents. In that case the circuit is not compensated, so the mains current will rise.
Regular control of mains current and/or power factor is advisable.

5) Short-circuiting of the series capacitor

In fact there are no visible signs or critical effects when the series capacitor is short-circuited. The lamp circuit will function normally, but only the power factor will change and will shift.

3 Earth leakage

There are two different official earth classifications:

1) Protective earth (PE) with symbol ⏚, which must ensure safety in case of (human) contact with accessible metal parts that can become live, e.g. at the end of the life of a component.
2) Functional earth with symbol ⏚, necessary to connect for reasons other than safety.

With electromagnetic lamp control gear we only have to deal with protective earthing, which is permissible by mounting the gear to an earthed metal component.
Capacitors in metal housings can often be mounted by means of a metal stud (see Fig. 141).

Fig. 141. Typical capacitor with metal stud fixing.

Earth leakage currents in lighting circuits depend on the quality of all system components and on the circumstances (humidity, dust, age). With respect to luminaires, IEC 598 restricts these currents to 0.5 or 1 mA, depending on the insulation classification. The earth connection may consist of an earth lead or the capacitance between the luminaire and its surroundings.
The earth leakage current of a ballast normally is very low: all ballasts undergo a high-voltage insulation test of 2500 V to check their insulation resistance. This can be checked in practice with a Megger (Megohm meter) of minimum 500 V DC, resulting in an insulation resistance of more than 2 Megohm. Tests with burning lamps can give earth leakage currents of about 1 to 2 mA per lamp circuit. In older installations these values can be somewhat higher due to humidity, dust, cable capacity or during the starting period. But the earth leakage current never should be higher than 5 mA per lamp circuit.
There are two different applications for earth leakage devices:
1) to protect people from direct contact with live parts, reacting to the current through the human body; there are 10 and 30 mA devices,
2) to protect people and grounded installations, reacting to the direct current to earth; there are devices of 300 mA and higher.

3.19 *Fault finding*

When a lighting installation becomes inoperative, a complex, thorough, trouble-shooting procedure may prove overly time-consuming. In many cases, a simple check of the power switches, lamps and gear may provide the quickest response to the problem. In some cases, however, it may be necessary to isolate the problem systematically and perform complete electrical tests in order to restore the lighting properly. Besides, it is important to know if the installation or individual isolated lighting points did function well before the failure.
There are four basic causes of failures:
A: lamp-related: not starting, cycling, too bright or dim,
B: gear-related: too hot or damaged ballast, capacitor, starter,
C: installation-related: cable too hot, terminals or lampholder damaged, blown fuses, contactors or circuit breakers switched,
D: supply-voltage-related: too high, too low, wrong frequency, bad voltage waveform.

There are also four basic trouble-shooting methods:
1. visual inspection,
2. quick fix for restoring lighting,
3. trouble-shooting checklist,
4. electrical tests.

1A: Visual inspection of lamps

End-of-life of lamps is characterized by low light output and/or different colours. Visual signs include blackening at the ends of the arc tube and electrode tip deterioration.

Additional checks:

- broken lamp pins,
- broken or loose electrodes in lamp tube,

- tube blackening,
- lamp type and wattage must correspond to that required by ballast label,
- lamp orientation designation incorrect for application (base up, base down).

1B: Visual inspection of components

- damaged ballast, starter or capacitor,
- evidence of moisture or excessive heat,
- loose, disconnected, pinched or frayed leads,
- incorrect wiring,
- ballast, starter and capacitor must correspond with lamp type and lamp wattage for the actual mains supply voltage.

1C: Visual inspection of installation

- incorrect wiring,
- blown fuses, switched circuit breakers or contactors,
- hot cables,
- damaged lampholders.

1D: Visual inspection of mains supply

Verify that the correct line voltage is being supplied and that phase and neutral are connected in accordance with the the wiring diagram.

2: Quick fix for restoring lighting

After the visual inspection and repair, replace any defective component, starting with the lamp and glow-switch starter.

3: Trouble-shooting checklist

When, after following points 1 and 2, a failure still exists, some tests will have to be carried out.

Fault I: lamp shows bright flash and does not ignite again.
• *Possible cause:*
- no ballast, incorrect ballast, short-circuited ballast,
- capacitor across the lamp instead of across the mains.

Fault II: newly replaced lamp does not ignite.
• *Action:*
- disconnect starter and measure mains voltage and open-circuit voltage at the lampholder. These must both be equal in case of a linear coil,
- if equal, replace the starter,
- if not equal, replace the ballast,
- if equal and not igniting with new starter and lamp, check lampholder and circuit contacts.

Fault III: lamp remains in glow stage, does not ignite properly or only lamp ends (electrodes) do emit some light.
• *Possible cause:*
- lamp was damaged in previous overload,
- starter defect or short-circuited.

Fault IV: lamp flickers.
• *Possible cause:*
- lamp operating voltage too high, end of lamp life,
- low supply voltage, check ballast connection,
- burning position out of specification.

Fault V: strong blackening of lamp, light output reduction.
• *Possible cause:*
- overload operation,
- wiring / ballast defect,
- capacitor across lamp instead of mains,
- end of lamp life.

Fault VI: fuse acting shortly after switch-on.
• *Possible cause:*
- fuse rating too low or not slow-acting type,
- wiring defect, overload operation.

Fault VII: colour differences in lamp colour.
• *Possible cause:*
- strongly varying burning positions in an installation,
- underload,
- lamps of different operating age or different suppliers,
- lamps of different colours used.

4: Electrical tests

Voltage and current measurements present the possibility of exposure to hazardous voltages and should be performed only by qualified personnel. To measure the correct effective values, true RMS voltmeters have to be used. Measurements with non-true RMS meters can give up to 50 per cent lower values, especially during measurements of the lamp voltage or other non-sine-wave voltages (see table below).

Description	Waveform	True RMS	Peak RMS calibrated	Average RMS calibrated
Sine wave		100	100	100
Square wave		100	71	111
Triangular wave		100	120	96
Single-phase electronic load current		100	200	50
Single-phase electronic plus 30 % linear load		100	166	83

The **parallel compensating capacitor** can be measured in two ways:
1) Measure mains current and lamp current.
   If both are the same, the capacitor is open-circuit and has to be replaced.

If the mains current is about half the lamp current, the capacitor is in order, resulting in a power factor of approx. 0.9.

2) Disconnect capacitor from circuit and discharge by short-circuiting terminals.
   Check capacitor with ohmmeter set at highest resistance scale.
   If the meter indicates a very low resistance which then gradually increases, the capacitor is in order.
   If the meter indicates a very high resistance which does not diminish, the capacitor is open-circuit and should be replaced.
   If the meter indicates a very low resistance which does not increase, the capacitor is short-circuited and should be replaced.
   This method can also be used for the series capacitors.

Measurement of the starting pulse voltage of a **starter** is beyond the capability of most instruments available in the field, due to the high peak voltages. The practical way is to replace the suspect starter by another one.

Measurements on the **ballast** can be done in two steps after disconnecting the ballast from the circuit:

1) Check with ohmmeter on the terminals. Values should be low (15 to 200 Ω, depending on lamp power). If the value is high, the ballast is open-circuit.
2) Connect ballast on the mains supply (well fused!) and measure the short-circuit current. This should be approx. 1.5 times the nominal lamp current.

Measurements of the **lamp electrodes** can be done at the 4-pin versions with a standard ohmmeter. The resistance of the electrodes varies for the different lamp types, but is less than 50 Ω when cooled down.

Measurements on the **lamp** in operation can only be done if the starter is not operative. As the lamp voltage is not a sine wave and subject to the tolerances in the total circuit, measured lamp voltages only give a rough indication of correct functioning. The lamp current can be measured rather accurately.

Measurements of the **mains supply** normally involve the effective value of the supply voltage and mains current and sometimes the frequency. When pulses, interruptions, harmonics (wave form) can play a role, 'laboratory' instruments are necessary, preferably during a longer period while storing or noting the readings.
It is advisable to measure the various phase currents in an installation, in order to check the balance of the load. Also the measurement of the current in the neutral in a star network gives an indication of the quality of the total system. Due to harmonics in the lamp current, the current in the neutral is not zero, but should be 50....70 per cent of the phase currents. If the current in the neutral is higher than in the phases, the balance in the load is not correct or the mains supply waveform does not have a good sine wave. This can lead to overload of the neutral cable.

For safety and good ignition, earthing of the luminaires and the electrical system can be essential. Check the system's current to real earth (see section 5.3.18: Earth leakage). The voltage between real earth and the neutral conductor is not limited by safety regulations, but lies normally between 0 and 6 V.

Apart from these electrical tests, it has to be checked that all components are used within their specifications, with special attention to the maximum temperature.

3.20 ***Installation aspects***

- The live side of the mains must be connected to the ballast. As most ballasts are symmetrical there is no marked indication at the ballast terminals for the mains and lamp connection. Mixing up the ballast terminals can slightly influence the radio-interference level.
- In the total circuit, however, interchanged connection of phase and neutral terminals can cause higher radio interference, higher earth leakage currents and/or ignition problems.
- It is recommended that the bottom plate of the ballast be connected to earth, for example via a metal part of the luminaire. In case of end-of-life of the ballast, short-circuiting of the ballast windings to the metal laminations of the ballast will result in a blown mains fuse. The ballasts do not have a separate earth contact: earthing-while-mounting.
- In two- or three-phase networks with a neutral conductor, this neutral wire must have the same cross-section as the phase wires.
- Use stranded wire in places that are subjected to vibrations or where the wire must be able to bend in use, as in a spotlight.
- Most ballasts, starter- and lampholders are equipped with either single or double insert contacts, suited for solid core wire of 0.5 - 1.0 mm^2, which should be stripped properly.
- At ambient temperatures below 10 ºC closed luminaires should be used to avoid too low lighting levels.
- Circuits with glow-switch starters require long starting times at low temperatures. An earthed metal shield near the lamp will improve the starting process, shortening the starting time and increasing lamp life. This earthed metal shield can be the mounting plate for the ballast.
- Mount the ballast as close as possible to the lamp. Although the starter peak initially has a high value, its energy content is restricted. Due to the high ohmic resistance of long installation wires, the starter energy can easily be lost. This can happen in particular in series circuits with two 'TL' 4-6-8 W lamps.
- Preferably mount ballasts on metal surfaces for good heat transmission. If the ballast has to be mounted on heat-isolating material (wood), the ▽F type ballast should be used.
- In outdoor applications SL lamps should be used inside an enclosed luminaire. This is to prevent moisture from creeping into the lamp.
- SL lamps cannot be dimmed as this will reduce lifetime considerably. Also, the dimming circuit in which the lamps are used can be damaged.

3.21 *Non-standard supply voltages*

In combination with the correct gear, fluorescent lamps can function perfectly on a wide range of supply voltages. The luminaire itself is not limited to certain supply voltages either.
For non-standard voltages appropriate gear components should be selected:

- Ballasts have to be designed for the proper supply voltage and frequency and for the chosen lamp type. So ballasts for a mains supply frequency of 50 Hz are different from those for 60 Hz, even if the mains voltage and the lamp type are the same. If the desired ballast type is not in the standard Philips range, information can be obtained from the local Philips organisation.
- Starters are related to lamp type, ballast and supply voltage. The Philips range of starters cannot be used for other voltages than those for which they are specified. All starters are suited for 50 and 60 Hz.
- Capacitors are specified by their voltage and capacitance (in µF). As long as the voltage is lower than the marked capacitor voltage, the capacitor can be used. There is no difference in the capacitor for 50 or 60 Hz supply voltage frequency. The necessary capacitance can be calculated and is, for example in the case of parallel compensation, 5/6 smaller for 60 Hz supplies than for 50 Hz supplies.
- Filter coils are related to a capacitance (in µF) and a frequency. As long as the power supply voltage is lower than the marked filter coil voltage, the filter coil can be used.
- In large lighting installations, in most cases there is a possibility to transform the non-standard voltage centrally into a standard voltage. In small projects a local solution has to be found.
- If the power supply voltage for fluorescent lamp circuits is generated by a separate motor/generator set (e.g. for emergency lighting), special attention must be paid to the right choice of the generator/ alternator type. Not all types of generators can correctly handle the changing power factor and/or the harmonics in the phase and neutral current. Minimum requirements can be supplied on request.

3.22 *Maintenance*

Gear components are in fact designed to be maintenance-free. Regularly checking the tightness of the screw terminals can prevent problems caused by open circuits or sparking. Loose mounting screws at the ballasts can cause hum. In very dusty surroundings the ballast can become overheated and should be cleaned.
It is advisable to renew the glow-switch starter(s) at the moment of lamp replacement.
The voltage required for ionization during the starting process may be affected by dirty lamps, excessive moisture or a combination of both. In installations with considerable dust accumulation, the lamps have to be cleaned regularly for reliable starting. Also clean the equipment at lamp replacement.